Volume 12, Number 6
November–December 2004

ISSN: 0869-5938

STRATIGRAPHY AND GEOLOGICAL CORRELATION

English Translation of *Stratigrafiya. Geologicheskaya Korrelyatsiya*

Editor-in-Chief
Boris S. Sokolov

http://www.maik.ru

Journal of the Fundamental and Applied Aspects of Stratigraphy and the Correlation of Geologic Events and Processes in Time and Space

МАИК "НАУКА/INTERPERIODICA" PUBLISHING

Stratigraphy and Geological Correlation

(Stratigrafiya. Geologicheskaya Korrelyatsiya)

ISSN: 0869-5938

Editor-in-Chief

Boris S. Sokolov

Member of the Russian Academy of Sciences,
Counsellor of the Presidium of the Russian Academy of Sciences (RAS)
Address for correspondence:
Staromonetnyi per. 22, Moscow, 109180 Russia
Phones: 7 (095) 951-2164; Fax: 7 (095) 951-0443

Deputy Editor-in-Chief

Mikhail A. Semikhatov

Member of the Russian Academy of Sciences,
Head of Laboratory, Geological Institute, RAS
E-mail: semikhatov@ginras.ru

Assistant Editor

Victor A. Zakharov

Dr. Sci. (Geol.–Min.), Chief Scientist, Geological Institute, RAS
E-mail: mzarctic@mtu-net.ru

EDITORIAL BOARD

Mikhail A. Akhmet'ev
Dr. Sci. (Geol.–Min.),
Head of Laboratory, Geological Institute, RAS
akhmetev@ginras.ru

Aleksandr S. Alekseev
Professor, Dr.Sci. (Geol.–Min.),
Department of Geology,
Moscow State University
aaleks@geol.msu.ru

Mikhail N. Alekseev
Dr. Sci. (Geol.–Min.), Chief Scientist,
Geological Institute, RAS
alekseev@ginras.ru

Ivan A. Basov
Dr. Sci. (Geol.–Min.), Laboratory Chief,
Geological Institute, RAS
basov@ilsan.msk.ru

Elena V. Bibikova
Dr. Sci. (Geol.–Min.), Chief Scientist,
Vernadsky Institute of Geochemistry
and Analytical Chemistry, RAS
bibikova@geokhi.ru

Nikolai M. Chumakov
Dr. Sci. (Geol.–Min.),
Chief Scientist, Geological Institute, RAS
chumakov@ginras.ru

Mikhail A. Fedonkin
Corresponding Member of RAS, Laboratory Chief,
Paleontological Institute, RAS
mfedon@paleo.ru

Yurii B. Gladenkov
Dr. Sci. (Geol.–Min.),
Head of Laboratory, Geological Institute, RAS
gladenkov@ginras.ru

Alexei B. Herman
Can. Sci. (Geol.–Min.),
Geological Institute, RAS
herman@ginras.ru

Victor E. Khain
Member of RAS, Chief Scientist,
Geological Institute, RAS Phone: 7(095)242-44-47

Kirilla I. Kuznetsova
Dr. Sci. (Geol.–Min.), Chief Scientist,
Geological Institute, RAS
kuznetsova@ginras.ru

Mikhail G. Leonov
Dr. Sci. (Geol.–Min.), Laboratory Chief,
Geological Institute, RAS
mleonov@ginras.ru

Lidiya A. Nevesskaya
Dr. Sci. (Biol.), Laboratory Chief,
Institute of Paleontology, RAS
lenin33@paleo.ru

Aleksandr G. Ponomarenko
Dr. Sci. (Biol.), Chief Scientist,
Institute of Paleontology, RAS
vtopor@paleo.ru

Aleksei Yu. Rozanov
Corresponding Member of RAS,
Director, Institute of Paleontology, RAS
aroza@paleo.ru

Aleksandr I. Zhamoida
Corresponding Member of RAS,
Russian Geological Institute, St. Petersburg
Phone: 7(812)328-92-58

Staff Editor Tamara V. Trishkina

Editor of the English Translation Anatolii Ya. Sharas'kin, Dr. Sci. (Geol.–Min.)

SCOPE

Stratigraphy and Geological Correlation (*Stratigrafiya. Geologicheskaya Korrelyatsiya*) is the only journal in the world designed to provide comprehensive coverage of the fundamental and applied aspects of stratigraphy and the correlation of geological events and processes in time and space. Articles are based on the results of multidisciplinary research and are directed toward researchers, university professors, students, and geologists interested in understanding stratigraphy and the chronological features of the world's geological record.

Stratigraphy and Geological Correlation is abstracted and/or indexed in *Petroleum Abstracts*, *Research Alert*, *SciSearch*, *Current Contents* (*Physical, Chemical*, and *Earth Sciences*) and *World Translations Index*.

SUBSCRIPTION OFFICE

INTERPERIODICA
P.O. BOX 1831, BIRMINGHAM, AL 35201-1831 USA
PHONE: (800) 633-4931; (205) 995-1567 (outside US and Canada)
FAX: (205) 995-1588

PUBLISHER

INTERNATIONAL ACADEMIC PUBLISHING
COMPANY "NAUKA/INTERPERIODICA"
PROFSOYUZNAYA UL. 90, MOSCOW, 117997 RUSSIA
PHONE: 7 (095) 336-1600; FAX: 7 (095) 336-0666
E-mail: compmg@maik.ru
Web Site: http://www.maik.ru

SUBSCRIPTION PRICES (2004, Volume 12, 6 issues)

US $1365.00 (North America), $1564.00 (elsewhere). Subscriptions may be entered at any time. Orders may be placed at agencies or directly. Cancellations not allowed except for duplicate payment. Prepayment required. Advance payment required in US$/US bank. MasterCard/Visa accepted. Make checks payable to *Stratigraphy and Geological Correlation* or Interperiodica.

Stratigraphy and Geological Correlation (ISSN: 0869-5938) is published bimonthly for US $1365.00 (North America), outside North America for $1564.00 per year by MAIK "Nauka/Interperiodica", 5724 Hwy. 280 East, Birmingham, Alabama 35242-5724 USA. Periodical postage paid at Birmingham, Alabama, and additional mailing offices. POSTMASTER: Send address changes to *Stratigraphy and Geological Correlation*, P.O. Box 1831, Birmingham, Alabama 35201 USA.

The journal was founded in 1993.

Original Russian Edition Copyright © 2004 by the Russian Academy of Sciences.
English Translation Copyright © 2004 by MAIK "Nauka/Interperiodica" (Russia).

Printed in the USA by Pleiades Publishing, Inc.

Contents

Vol. 12, No. 6, 2004

Simultaneous English language translation of the journal is available from MAIK "Nauka/Interperiodica" (Russia).
Stratigraphy and Geological Correlation ISSN 0869-5938.

The Kislaya Guba Formation of the Late Archean Terskii–Allarechensk Greenstone Belt (Kola Peninsula, Russia): Stratotype and U–Pb Age
V. V. Chashchin, T. B. Bayanova, and N. V. Levkovich 541

Microfossils and Riphean Stratigraphy in the North European Platform (Mezen Syneclise)
A. F. Veis†, D. L. Fedorov, Yu. T. Kuzmenko, N. G. Vorob'eva, and E. Yu. Golubkova 553

Geochronology and Correlation of Mesozoic Magmatic Complexes in the Northern Margin of the Amurian Superterrane
A. A. Sorokin, V. A. Ponomarchuk, A. P. Sorokin, and S. K. Kozyrev 572

Stratigraphic Position of the Albian and Late Cretaceous Floras in Southern Mongolia
N. M. Makulbekov 588

The Mezino-Lapshinovka Reference Section of the Upper Cretaceous and Problems of Santonian–Campanian Boundary in Saratov Area near the Volga River
A. G. Olfer'ev, A. S. Alekseev, V. N. Beniamovskii, V. S. Vishnevskaya, A. V. Ivanov, E. M. Pervushov, V. B. Sel'tser, V. M. Kharitonov, and E. A. Shcherbinina 603

New Data on the Middle Miocene Biostratigraphy (Nannofossils, Mollusks) and Lithology of the Tamanskii Peninsula and Western Ciscaucasia
L. A. Golovina, I. A. Goncharova, and Yu. V. Rostovtseva 637

Author Index to Volume 12, 2004 647

Dear author,

Starting in 2005, Pleiades Publishing, Inc., the publisher of the English version of this journal, will conclude copyright transfer agreements with the authors of papers accepted for publication.

To simplify your interaction with the editorial board, please fill in two copies of the copyright transfer agreement and submit them together with the manuscript. A copyright transfer agreement form can be downloaded at www.maik.ru. This is an adhesion agreement.

The copyright transfer agreement (2 copies) properly filled and signed can be submitted to the editorial board of the journal personally or:

(a) by post
(b) by e-mail (PDF file) or fax; the original must be subsequently mailed by post.

Publisher

Stratigraphy and Geological Correlation, Vol. 12, No. 6, 2004, pp. 541–552. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 12, No. 6, 2004, pp. 3–15.
Original Russian Text Copyright © 2004 by Chashchin, Bayanova, Levkovich.
English Translation Copyright © 2004 by MAIK "Nauka/Interperiodica" (Russia).

The Kislaya Guba Formation of the Late Archean Terskii–Allarechensk Greenstone Belt (Kola Peninsula, Russia): Stratotype and U–Pb Age

V. V. Chashchin,* T. B. Bayanova, and N. V. Levkovich****

**Open Joint-Stock Company Central Kola Expedition, Monchegorsk, Russia*

***Geological Institute, Kola Scientific Center, Russian Academy of Sciences, Apatity, Russia*

Received December 24, 2002; in final form, November 19, 2003

Abstract—The Kislaya Guba Formation studied in the Near-Imandra synform of the Late Archean Terskii–Allarechensk greenstone belt is characterized. The basal, approximately 300-m-thick horizon of the formation is composed of amphibole to amphibole–biotite plagioschists and of amphibolites enclosing up to seven lenticular bodies of polymictic conglomerate each from 1.5 to 40 m thick. The formation structure is divisible in two large rhythms based on changes in the rock composition. The lower rhythm about 1000 m thick is represented by alternating biotite–amphibole plagiogneisses, amphibolites, and biotite plagioschists, which are replaced upward by sequence of alternating amphibole, biotite–amphibole, and two-mica plagioschists. The upper rhythm at least 2000 m thick corresponds to the middle and upper portions of the formation. It is differentiated, represented by amphibolites and amphibole, biotite–amphibole, biotite, and two-mica plagioschists successively replacing each other upward in the section. The formation thickness is close to 3000 m in total. Some rocks of the formation bear signs of their volcanic origin. The studied section is proposed to be the formation stratotype. Rocks of the Kislaya Guba Formation ranging from basaltic to rhyolitic composition correspond to differentiated K–Na volcanics of the tholeiitic and calc-alkaline series. The U–Pb age of zircons from acidic metavolcanics crowning the formation section is estimated to be 2178 ± 10 Ma from the upper intercept of discordia with concordia.

Key words: Kislaya Guba Formation, basal conglomerates, metabasalts, metadacites, tholeiitic and calc-alkaline series, U–Pb dating, Terskii–Allarechensk greenstone belt, Kola Peninsula.

INTRODUCTION

The Upper Archean Terskii–Allarechensk greenstone belt is a largest structure of this kind in the Kola Peninsula. It extends in the northwestern direction for over 400 km (*Greenstone Belts...*, 1988) and separates two largest structures of the region: the Kola block and Belomorian mobile belt (Fig. 1), being referred to the Upper Lopian Erathem (2800–2500 Ma) of the Upper Archean Eonothem. North of the belt, there is the Upper Proterozoic Pechenga–Imandra–Varzuga rift zone that is conformed to the belt structural plan. The belt consists of the Kaskam, Allarechensk, Near-Imandra, Near-Khibiny, Munozero, and other synform and monoclinal structures (*Greenstone Belts...*, 1988). The best studied among them is the Near-Imandra synform, where the most complete section of supracrustal rocks is established.

GEOLOGICAL STRUCTURE OF THE NEAR-IMANDRA SYNFORM

The structure extends from the western coast of Lake Bol'shaya Imandra to southern and eastern spurs of the Glavnyi (Main) Ridge (Fig. 1). Based on lithology, four units are traditionally distinguished within this structure from the base upward: the Voche-Lambina succession and Kislaya Guba, Vite Guba, and Arvarench formations. The *Voche-Lambina succession* is traceable as a belt 0.6 to 3 km wide from the northern coast of Lake Ekostrovskaya Imandra on the east to southern spurs of Glavnyi Ridge on the west (Fig. 1). The succession is composed of alternating amphibolites and biotite, epidote–biotite, biotite–amphibole, and amphibole–biotite plagiogneisses. The plagiogneiss layers of different composition vary in thickness from 1–2 to 10–20 m, and amphibolite strata are from 0.8 to 35 m thick; the total thickness of the unit is 400–650 m. It is noteworthy that amphibolite interbeds gradually become more abundant and thicker upward in the section, thus suggesting the acid-to-basic compositional trend of the rocks. Amphibolites and amphibole–biotite plagiogneisses enclose rare amygdaloidal relicts indicative of their volcanogenic origin.

The *Kislaya Guba Formation* is mapped in the Near-Imandra zone that is 4 to 6 km wide and extends over 25 km from Lake Bol'shaya Imandra on the east to eastern slopes of the Glavnyi Ridge on the west, where it is truncated by a gabbro–anorthosite intrusion (Fig. 1).

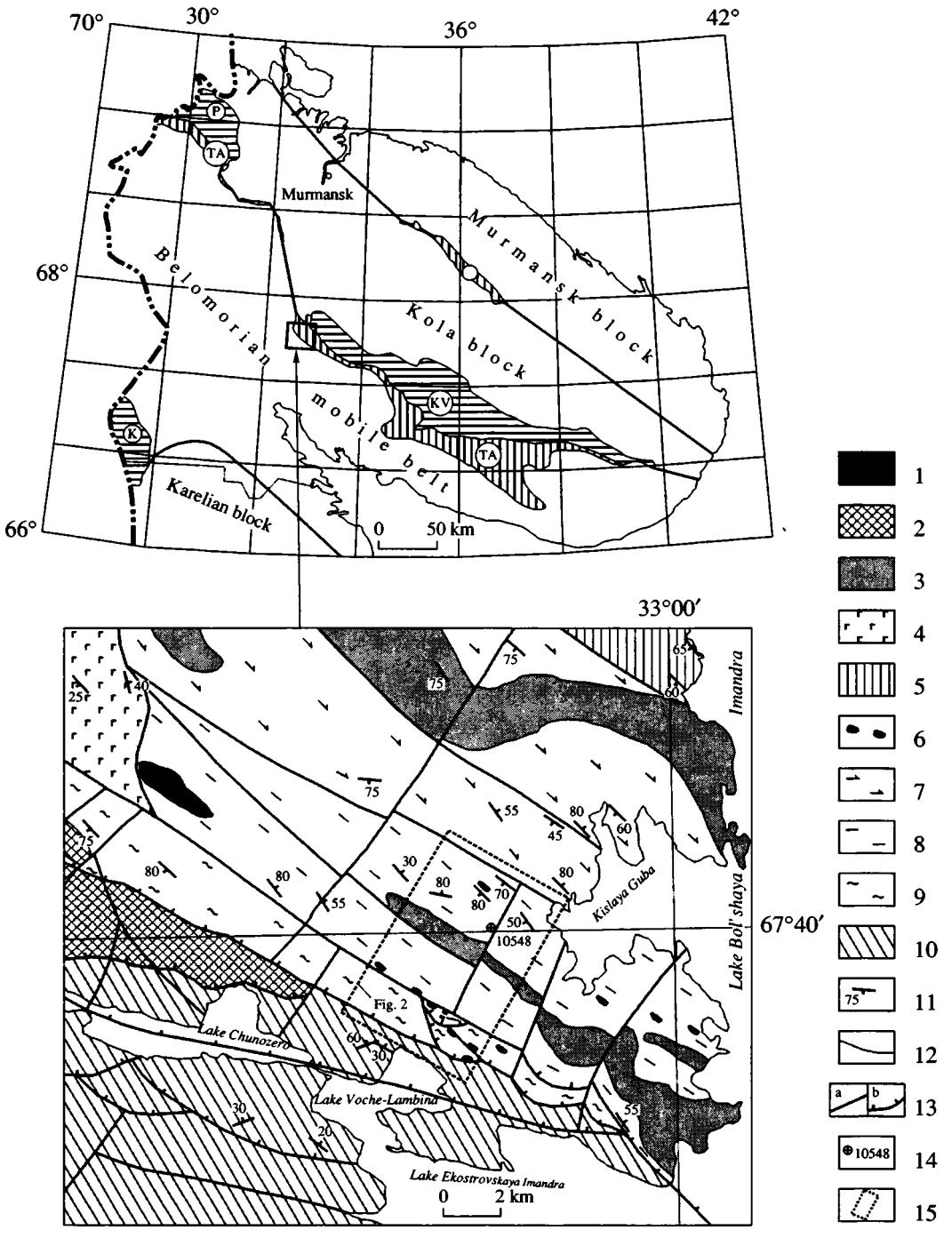


Fig. 1. Schematic geological map of the Kislaya Guba area: (1) Early Proterozoic (Late Karelian) clinopyroxenite intrusion of Lake Tulpjavr area; (2–4) Early Proterozoic (Early Karelian) gabbro–norites of the Nyark-Tundra massif (2), gabbroids of the Imandra lopoliths (3), and gabbro–anorthosites of the Glavnyi Ridge(4); (5) Lower Proterozoic volcanogenic–sedimentary rocks of the Imandra–Varzuga rift zone; (6) Upper Archean metamorphosed ultramafics of the Voche-Lambina Complex; (7–9) Vite Guba (7) and Kislaya Guba (8) volcanogenic formations and Voche-Lambina Sequence (9) of the Upper Archean (Upper Lopian) Terskii–Allarechensk greenstone belt; (10) Archean metamorphic and ultrametamorphic rocks of the Belomorian mobile belt; (11) attitude of foliation and gneiss bands; (12) geological boundaries; (13) strike-slip to normal (a) and thrust (b) faults; (14) sampling site for isotopic–geochronological study and its number; (15) contour of the stratotype area of the Kislaya Guba Formation (Fig. 2). Shading in scheme shows The Early Proterozoic Pechenga (P), Imandra–Varzuga (IV), and Kuolajarvi (K) rift zones are horizontally hatched in map the Kola Peninsula; vertical hatching denotes the Lopian Kolmozero–Voron'e (KV) and Terskii–Allarechensk (TA) greenstone belts; arrow points to area of the Kislaya Guba Formation.

The formation is separated from the underlying Voche-Lambina succession by a stratigraphic unconformity marked by basal conglomerates (Latyshev, 1984). The Kislaya Guba Formation characterized in detail below is composed of amphibolites and amphibole–biotite, biotite–amphibole, biotite, and two-mica plagiogneisses. The structural analysis shows that rocks of the Kislaya Guba Formation approximately 3000 m thick in total form most likely an asymmetrical synform with the truncated northern limb (Fig. 2).

The *Vite Guba Formation* is exposed in the central part of the Near-Imandra structure northeast of distribution area of the Kislaya Guba Formation (Fig. 1). It is separated by NW-trending faults from the underlying Kislaya Guba Formation on the south and Lower Proterozoic volcanics of the Imandra–Varzuga zone on the north. The formation is largely composed of amphibolites and amygdaloidal metabasalts, which grade upward into amphibole to biotite–amphibole plagiogneisses and locally into biotite and two-mica plagiogneisses. These compositional changes characterize the basic-to-acid evolutionary trend of the formation rocks. The presumable total thickness of the formation is close to 2000 m.

The *Arvarench Formation* crowns the section of the Near-Imandra structure. Rocks of the formation are exposed within an area 7 × 6 km, which is located eight kilometers away northward from that shown in Fig. 1 between volcanics of the Imandra–Varzuga zone on the east and Early Proterozoic gabbroids of the Monchetundra massif on the west and north. The formation section begins with basal polymictic conglomerate member overlain by acidic metavolcanics approximately 600 m thick constituting the largest part of the formation and corresponding in composition to metamorphosed amygdaloidal rhyodacite, subordinate dacites, and rhyolites. The basal horizon of boulder–pebbly conglomerates, which is approximately 50 m thick in total, extends for approximately 500 m. Some autonomous lenticular bodies of the horizon are of a rhythmic structure because of upward gradation from large-boulder to pebbly–gravely material. Clasts constituting up to 40–50% of the member volume are represented by biotite plagiogranites and subordinate granodiorites and quartz diorites (Gilyarova; 1972; Luneva, 1977). Granitoids of the basement exposed in the erosion window 2 km north of the Arvarench Formation distribution area probably underlie basal conglomerates and are the source of their clastic material. In the matrix of conglomerates, acidic volcanics are metamorphosed into biotite–amphibole, epidote–biotite, and chlorite–biotite plagioschists.

Faults inside the Near-Imandra structure are of different orientation and kinematics. In addition, numerous Late Archean and Early Proterozoic mafic–ultramafic intrusions are characteristic of the structure (Fig. 1).

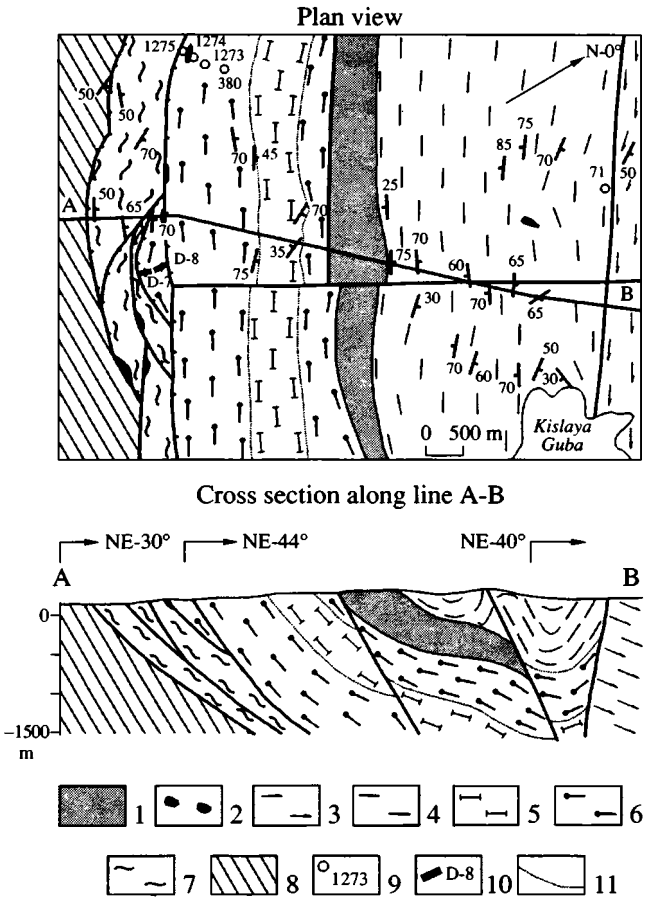


Fig. 2. Geological scheme and profile of stratotype area of the Kislaya Guba Formation: (1) gabbroids of the Imandra lopolith; (2) Late Archean metaultrabasite intrusions of the Voche-Lambina Complex; (3) Vite Guba Formation of the Upper Archean (Upper Lopian) Terskii–Allarechensk greenstone belt; (4) biotite, epidote–biotite, and two-mica plagiogneisses, (5) amphibolites and amphibole plagioschists, and (6) biotite–amphibole plagioschists of the Kislaya Guba Formation; (7) Voche-Lambina Sequence; (8) Archean metamorphic and ultrametamorphic rocks of the Belomorian mobile belt; (9) boreholes and their numbers; (10) trenches and their numbers; (11) facies boundaries.

Among all stratigraphic units distinguished in the Near-Imandra structure, the Kislaya Guba Formation most variable and contrasting in lithology is relatively well studied that opens an opportunity to decipher the internal structure and estimate the time-range of the unit. Precisely these aspects are considered in this work.

N. A. Ostrovskii was first to define in 1960 the Kislaya Guba Formation as an autonomous stratigraphic unit within the so-called Tundrovaya Group. Later on, the formation was described in the southern periphery of the Imandra–Varzuga zone (Kharitonov, 1966; Potrubovich *et al.*, 1967; Gilyarova, 1972). In the eponymous bay area of Lake Bol'shaya Imandra, rocks of the Kislaya Guba Formation were referred later on to

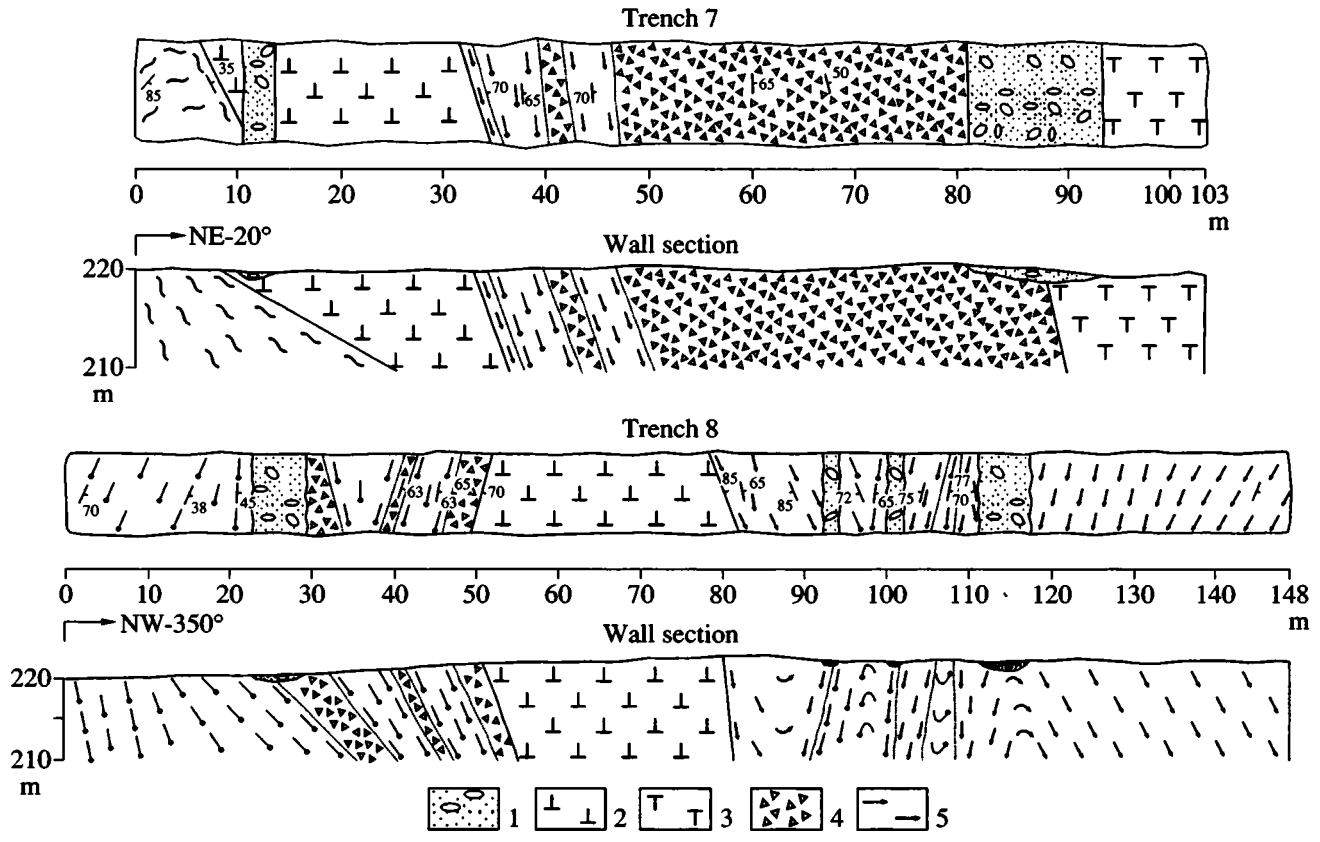


Fig. 3. Cross sections of the lower portion of the Kislaya Guba Formation: (1) Quaternary sediments; (2) metamorphosed orthopyroxenites and harzburgites of the Voche-Lambina complex; (3) gabbro–norites; (4) conglomerates; (5) hornblende amphibolites, locally with garnet (other symbols as in Fig. 2).

the undivided Kola–Belomorian complex (*The Imandra–Varzuga Zone...*, 1982). North of the Lake Voche-Lambina, Latyshev (1984) described the lower part of the formation as a synonymous group overlying with a stratigraphic unconformity the Voche-Lambina Group.

The stratigraphic position of conglomerates and related rocks in a stratified sequence exposed in the Lake Voche-Lambina and Kislaya Guba areas area is debatable. Some researchers (Bogdanov *et al.*, 1976; Latyshev (1984) considered conglomerates as corresponding to the base of the Kislaya Guba Formation, whereas T.F. Negrutsa referred them to supracrustal complex of the Voche-Lambina geodynamic polygon. The rocks enclosing conglomerates, which are approximately 500 m thick, was ascribed to succession IV corresponding to the upper part of that complex (*The Voche-Lambina Archean...*, 1991).

The above brief review of standpoints concerning position of the Kislaya Guba Formation lower part shows that the unit is of intricate structure and that some rocks are ambiguously referred to different subdivisions of the Terskii–Allarechensk greenstone belt. We attempted to resolve existing contradictions based on data available for the Kislaya Guba Formation reference section. Characteristics of the latter are inferred from all the materials concerning the formation structure, primarily on data obtained in the course of geological mapping (Scale 1 : 50000, report by A.B. Zaitsevskii of 1975), and from our original observations during field works and geological survey in the Monchegorsk ore area (works on new generation of State Geological Map, scale 1 : 200000). During these works, the most complete section of the Kislaya Guba Formation was studied in the best-exposed part of the Near-Imandra structure. To determine the formation age, the U–Pb dating of relevant rock was performed at the Laboratory of Geochronology and Isotope Geochemistry of the Geological Institute, Kola Scientific Center of the Russian Academy of Sciences.

STRUCTURE OF THE KISLAYA GUBA FORMATION

The basal, lower, middle, and upper parts are distinguished in the formation. As it was observed in trunk trenches 7 and 8 (Fig. 3), the basal horizon of the formation up to 300 m thick is represented at the contact with the underlying Voche-Lambina succession by stratiform bodies 4 to 40 m thick of amphibole and amphibole–biotite plagioschists and by amphibolites,

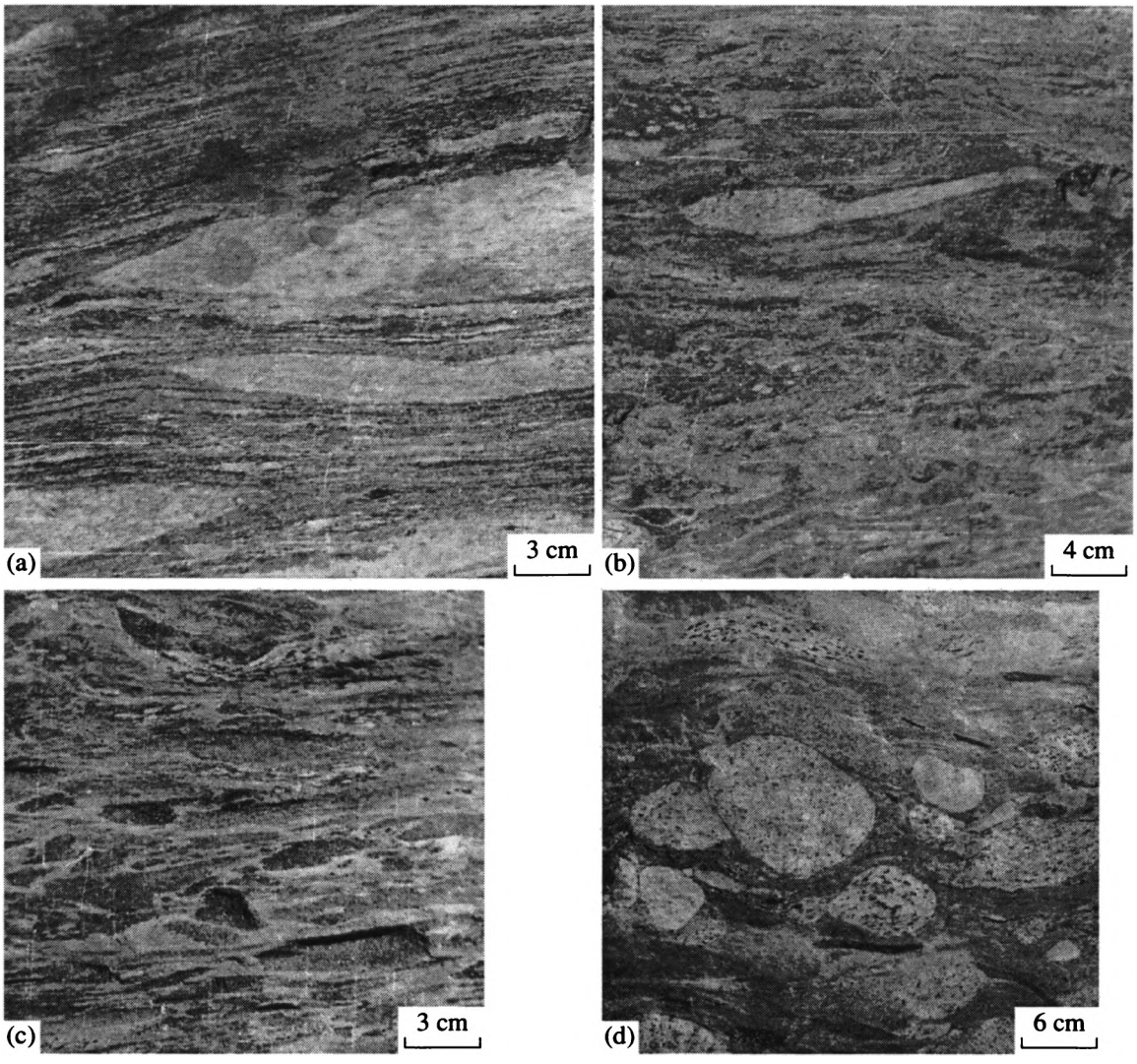


Plate I. Conglomerates from the Lake Voche-Lambina area: (a) intensely foliated (Trench 7, 40.8 m); (b) partly foliated with rare well-preserved plagiogranite fragments (Trench 7, 62.0 m); (c) foliated with prevalent rocks of the Voche-Lambina Sequence among clasts (Trench 7, 63.5 m); (d) slightly foliated with prevalent plagiogranites, diorites, amphibolites, and plagiogneisses of the Voche-Lambina Sequence among clasts (Trench 8, 48.0 m).

which are intercalated with lenses of polymictic conglomerates (Bogdanov *et al.*, 1976; *The Voche-Lambina Archean...*, 1991). In total, seven conglomerate lenses 1.5 to 40 m thick are established, five of which are encountered in trenches 7 and 8 (Fig. 3). Contacts of conglomerates with under- and overlying rocks are either tectonic or normal stratigraphic. Conglomerates present at several levels indicate likely an intense synsedimentary volcanic activity.

In the lower part of the unit exposed in Trench 7, rocks are moderately to intensely foliated (Plate Ia–Ic). Nevertheless, despite their deformation, it is established that abundance of detrital material regularly decreases upward in the section of thickest conglomerate lens. The upper part of the basal unit is exposed in Trench 8, where three conglomerate lenses show distinct rhythmical alternation of boulder, boulder–pebbly, and gravel material decreasing in abundance upsection (Fig. 3). Individual rhythms range in thickness from 0.5 to 1.5 m (*The Voche-Lambina Archean...*, 1991).

Clasts in conglomerates are mainly represented by biotite plagiogranites and amphibole quartz diorites (Plate Ia, Id), less frequently by amphibolites and biotite gneisses (Plate Ib, Ic). Biotite gneisses are similar in composition to their counterparts from the Voche-Lambina succession. Granitoid fragments were most likely derived from the Belomorian mobile belt located 1 km south, while amphibolite and plagiogneiss fragments represent erosion products of the Voche-Lambina succession located nearby.

The conglomerate matrix is composed of amphibole to biotite–amphibole plagioschists and amphibolites

Table 1. Chemical composition of rocks from the Kislaya Guba Formation

Sample / Component	* 1	* 2	1081400 3	* 4	1081500 5	488a 6	1081600 7	* 8	* 9	* 10	* 11	8711 12	* 13
SiO_2	48.14	52.64	56.06	56.66	56.81	57.20	57.22	58.45	58.70	59.99	60.35	66.24	68.68
TiO_2	0.82	0.85	0.71	1.03	0.82	0.94	0.94	1.03	0.62	0.56	0.84	0.70	0.91
Al_2O_3	14.99	14.14	14.89	13.66	15.06	12.95	13.97	13.28	14.11	13.59	13.05	11.94	12.19
Fe_2O_3	2.90	2.67	1.52	2.37	1.35	2.47	1.42	1.66	1.58	1.38	1.48	1.18	1.85
FeO	10.03	7.99	8.30	9.71	7.11	9.62	10.08	9.45	7.85	7.54	7.70	5.02	3.84
MnO	0.18	0.17	0.16	0.17	0.14	0.17	0.17	0.17	0.15	0.15	0.14	0.14	0.09
MgO	7.37	6.38	5.12	2.93	4.21	3.00	3.73	2.59	4.13	4.25	3.66	3.76	1.44
CaO	9.48	10.94	8.27	6.60	9.01	5.55	9.07	7.22	7.51	5.21	5.59	4.18	2.76
Na_2O	2.32	3.10	2.90	3.54	3.75	3.40	1.92	3.50	2.59	5.57	3.33	3.60	3.66
K_2O	1.27	0.62	1.21	1.35	0.87	2.20	0.48	0.96	1.26	1.15	1.9	2.00	3.18
P_2O_5	0.11	0.24	0.15	0.21	0.15	0.13	0.17	0.35	0.18	0.15	0.21		0.16
L.O.I.	2.09	0.89	0.56	1.01	0.44	1.94	0.40	1.35	0.76	0.76	1.12	1.55	0.55
H_2O-	0.15	0.00	0.29	1.06	0.11	0.24	0.20	0.03	0.18	0.20	0.13	0.05	0.18
K_f	63.7	62.6	65.7	80.5	66.8	80.1	75.5	81.1	69.5	67.7	71.5	62.2	79.8
Total	100.34	100.66	99.93	99.35	99.78	99.63	99.65	100.22	99.76	100.62	99.54	100.31	99.58

Note: (1, 2) amphibolites (metamorphosed basalts); (3–5) amphibole plagioschists (metamorphosed basaltic andesites); (6–11) biotite–amphibole plagiogneisses (metamorphosed andesites); (12) amphibole–biotite plagiogneiss (metamorphosed rhyodacites and rhyolites); (13–27) biotite and two-mica plagiogneisses (metamorphosed rhyodacites and rhyolite).

referred previously to succession IV of the Voche-Lambina geodynamic polygon (*The Voche-Lambina Archean...*, 1991). The content of detrital material in conglomerates varies from 10–15 to 40–45%. The rocks were thoroughly described by Bogdanov *et al.* (1976), Latyshev (1984) and Negrutsa (*The Voche-Lambina Archean...*, 1991). As was mentioned, some researchers referred these conglomerates to the Voche-Lambina succession (*The Voche-Lambina Archean...*, 1991), but presence of detrital material similar in composition to rocks of the Voche-Lambina succession and structural position evidence in favor of opinion of Latyshev (1984) who placed them at the base of the Kislaya Guba Formation.

Amphibolites and amphibole to biotite–amphibole plagiogneisses of the Voche-Lambina succession present among conglomerate clasts imply that rocks subjected to erosion experienced amphibolite-facies metamorphism prior to deposition of the Kislaya Guba Formation. Indeed, in the Ensk and Voche-Lambina segments of the Kola region, supracrustal complexes of the Lopian greenstone belts were metamorphosed under PT conditions of amphibolite grade (580–610°C and 6.3–9.4 kbar; *The Voche-Lambina Archean...*, 1991) 2744 Ma ago (Pozhilenko *et al.*, 1995). In contrast, rocks of the Kislaya Guba Formation were metamorphosed under conditions of the low-temperature amphibolite facies (Petrov *et al.*, 1984), and age of this event repeated for the Voche-Lambina succession is unknown.

The lower part of the Kislaya Guba Formation is penetrated by boreholes 1273–1275 (report by A.B. Zaitsevskii and others of 1975) and 380 (report by N.G. Dobrynina and others of 1970) (Fig. 2). It is composed of frequently alternating biotite–amphibole plagiogneisses, amphibolites, and biotite plagioschists (Borehole 1275), which grade upward into coarser alteration of amphibole, biotite–amphibole, and two-mica plagiogneisses with interbeds of amphibolites and garnet–amphibole–biotite plagiogneisses (boreholes 380, 1273, 1274). The integral thickness of drilled sections is at least 500 m, while beds of individual lithological varieties are from a few (Borehole 1275) to 10–40 meters thick. The total thickness of the Kislaya Guba Formation lower part is up to 1000 m.

Characterization of the formation middle part is based on field observations and data from rare trenches. In the basal interval approximately 500 m thick, it is composed of melanocratic amphibolites locally bearing garnet and clinozoisite, which grade upward into amphibole and biotite–amphibole plagiogneisses. The complete thickness of the latter is unknown because they are partly truncated by the gabbroid Imandra lopolith; presumably, plagiogneisses are 500 m thick (Fig. 2). The middle unit is crowned by biotite and two-mica (muscovitization?) and subordinate garnet–two-

1053105	1874	1855	*	488b	1054802	*	1054800	1053300	1926g	*	*	*	*
14	15	16	17	18	19	20	21	22	23	24	25	26	27
68.82	68.94	69.58	69.98	70.20	70.42	71.61	72.52	75.01	75.54	76.52	77.33	79.02	79.29
0.77	0.71	0.74	0.60	0.55	0.59	0.56	0.51	0.43	0.27	0.15	0.31	0.24	0.31
11.84	12.20	11.56	11.83	12.00	13.56	10.83	12.70	11.16	11.06	11.30	9.22	8.33	9.16
2.09	1.51	1.84	1.22	1.36	1.12	0.92	1.35	0.63	1.11	0.00	0.45	0.44	0.10
6.48	6.30	6.48	5.44	5.67	3.53	5.27	2.53	3.20	2.27	2.94	3.45	3.98	3.75
0.05	0.09	0.07	0.12	0.18	0.07	0.12	0.04	0.03	0.07	0.03	0.05	0.06	0.06
1.51	1.35	1.80	0.35	0.80	2.09	0.64	1.58	1.00	1.73	1.00	1.54	1.03	0.47
0.86	1.24	0.92	2.48	2.49	1.33	2.28	1.36	0.86	2.15	1.37	2.04	3.40	2.40
2.43	3.20	2.92	3.37	3.10	2.56	2.37	2.06	2.25	3.10	3.69	1.97	2.38	2.85
3.60	3.40	3.20	3.60	2.76	2.82	3.85	2.64	3.87	2.30	1.66	2.09	0.29	1.56
0.14	0.17	0.15	0.18	0.08	0.17	0.14	0.14	0.04		0.09	0.12	0.15	0.10
0.83	0.57	0.41	0.27	0.80	1.87	0.58	1.57	0.99	0.66	0.76	0.73	0.32	0.34
0.16	0.08	0.18	0.20	0.06	0.38	0.08	0.43	0.15		0.14			
85.0	85.3	82.2	95.0	89.8	69.0	90.6	71.1	79.3	66.1	74.6	71.7	81.1	89.1
99.49	99.73	99.72	99.71	99.99	100.20	99.42	99.20	99.47	100.26	99.90	99.43	99.76	100.43

Asterisk designates data from * The Voche-Lambina Archean Geodynamic Polygon of the Kola Peninsula... (1991), other samples were analyzed at the Chemical–Technological Laboratory of the Murmansk Geological–Prospecting Expedition and in the Open Joint-Stock Company Kola Geological and Laboratory-Informative Center (Apatity). ($K_f = (FeO + Fe_2O_3)/(FeO + Fe_2O_3 + MgO)$).

mica plagiogneisses with occasional relicts of plagioclase phenocrysts and amygdaloidal structures. The true thickness of these rocks is unknown; presumably, it is 500 m at least (Fig. 2).

The Kislaya Guba Formation upper part is penetrated to depth of 300 m by Borehole 71 drilled in the northern limb of the corresponding structure during geological–mineralogical survey (data by V.A. Zhitnikov of 1991). It is composed of alternating members of prevalent biotite plagioschists (60 m and thicker) and two-mica plagioschists (20–50 m thick), which enclose amphibole–biotite plagioschist beds up to 15 m thick. Numerous interlayers of partly chloritized biotite plagioschists (3–5 m thick) and alternating laminae (5–10 cm) of biotite–amphibole, amphibole–biotite, and amphibole plagioschists sometimes bearing garnet are present in the last beds. Contacts between rocks of different lithology are usually vague and gradual. The true thickness of the formation upper unit is unknown; presumably, it is at least 1000 m (Fig. 2).

Based on distribution of rocks (Fig. 2), the Kislaya Guba Formation can be divided in two large rhythms. The lower incomplete rhythm spans the formation lower part and is composed of alternating biotite to biotite–amphibole plagioschists and amphibolites. The upper most complete rhythm corresponding to the middle and upper parts of the formation is composed of amphibolites and amphibole, biotite–amphibole, biotite, and two-mica plagioschists successively replacing each others upward the section.

PETROCHEMISTRY

Relict amygdaloidal and porphyritic structures observable in different rock varieties of the Kislaya Guba Formation despite low-temperature metamorphic transformations of amphibolite grade (Petrov *et al.*, 1984) unambiguously indicates volcanogenic origin of this subdivision. Keeping this in mind, let us consider chemical composition of the formation based on 26 silicate analyses (Table 1). According to these data, rocks vary in chemical composition from basalts (SiO_2 = 48.14–52.64 wt %) to rhyolites (SiO_2 = 75.01–79.29 wt %; Fig. 4), i.e., they belong mainly to K–Na volcanics of tholeiitic and calc-alkaline series (Fig. 5). Characteristic of all the rocks is an elevated Fe index (Table 1, Fig. 6), while lowered Al_2O_3 content is typical of metarhyolites and metabasalt–metadacite series. Contents of other major components are the level of corresponding volcanic rocks. In the basic-to-acid series, Mg, Ca, Fe, and, to a lesser extent, Al contents regularly decrease (Fig. 6), while alkali content simultaneously increasing in a succession of metamorphic rocks from basalt to dacite then become reduced in rhyolites (Fig. 4).

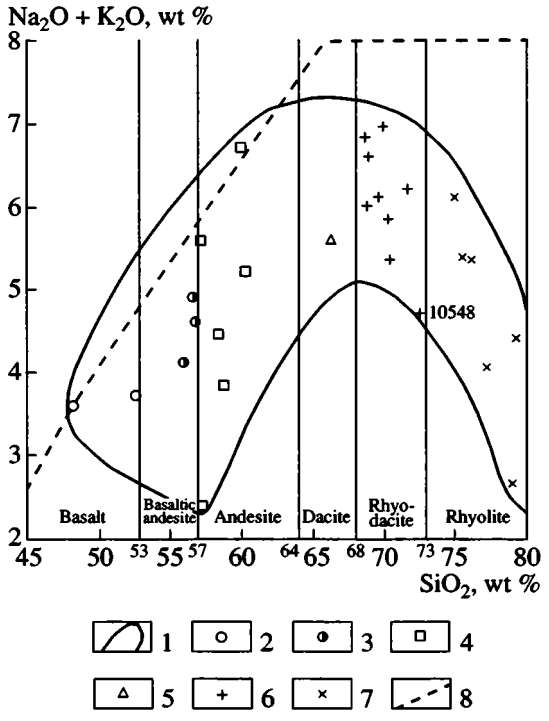


Fig. 4. Classification diagram SiO_2–(Na_2 + K_2O) for rocks of the Kislaya Guba Formation: (1) field of data points characterizing rocks of the Kislaya Guba formation; (2) amphibolites (metamorphosed basalts); (3) amphibole plagioschists (metamorphosed basaltic andesites); (4) epidote–biotite and biotite–amphibole plagioschists (metamorphosed andesites); (5) amphibole gneisses (metamorphosed dacites); (6) biotite–amphibole, biotite, and two-mica schistose gneisses (metamorphosed rhyodacites); (7) biotite and two-mica gneisses (metamorphosed rhyolites); (8) boundary between rocks of the normal and subalkaline series.

U–Pb AGE OF THE KISLAYA GUBA FORMATION

Of all the stratigraphic units of the Terskii–Allarechensk greenstone belt geochronological dates are known only for the Arvarench Formation. The U–Pb age of magmatic zircons from the formation is estimated to be 2707 ± 11 Ma (Pozhilenko *et al.*, 2000). In addition, the U–Pb zircon age of 2807 ± 7 Ma is determined for pebbles from conglomerates of the Kislaya Guba Formation (Kislitsyn *et al.*, 2000). This value is comparable with the age of 2814 ± 30 Ma obtained for granitoids of the Belomorian mobile belt, which are exposed in the southern periphery of the Voche-Lambina area (*The Voche-Lambina Archean...*, 1991).

To estimate the age of the Kislaya Guba Formation, a 100-kg sample of two-mica plagiogneisses corresponding by chemical composition to metamorphic dacite (Sample 10548, Fig. 4) was taken from the eponymous area of Lake Bol'shaya Imandra (Fig. 1). Five types of zircons, morphological habit of which suggests their magmatic origin, were extracted from the sample using separation in heavy liquid and standard electromagnetic technique.

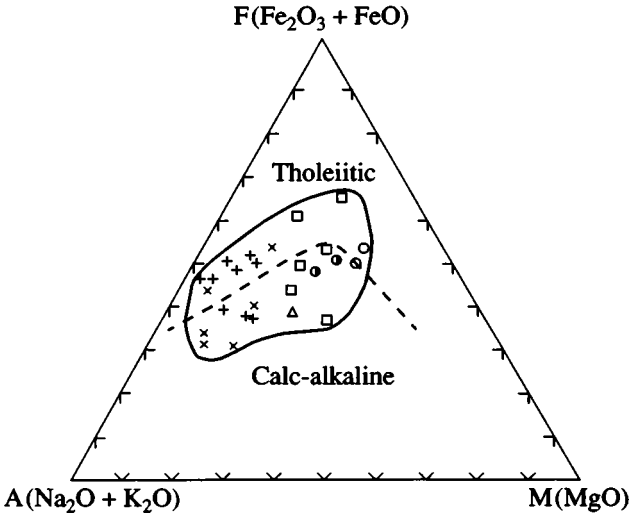


Fig. 5. AFM diagram for rocks of the Kislaya Guba Formation (symbols as in Fig. 4).

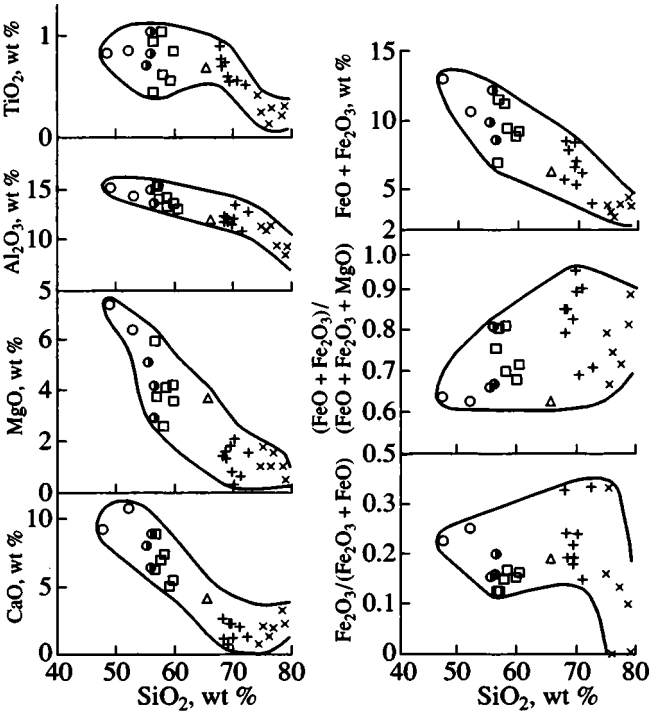


Fig. 6. SiO_2–oxide, SiO_2–(FeO + Fe_2O_3)/(FeO + Fe_2O_3 + MgO), and SiO_2–(FeO + Fe_2O_3) diagrams for rocks of the Kislaya Guba Formation (symbols as in Fig. 4).

Characteristic of zircons. The first generation is represented by prismatic zircon crystals with smoothed apexes and edges (Plate IIa, IIb, point 2 in Fig. 7 and Table 2). Crystals are transparent, with pinkish–lilac tint and glassy luster, 0.25–0.30 × 0.100–0.125 mm in size (elongation coefficient 2.5–3.5). Being immersed, these zircons show abundant, variably oriented fissures with haziness and dark films along them and occasional

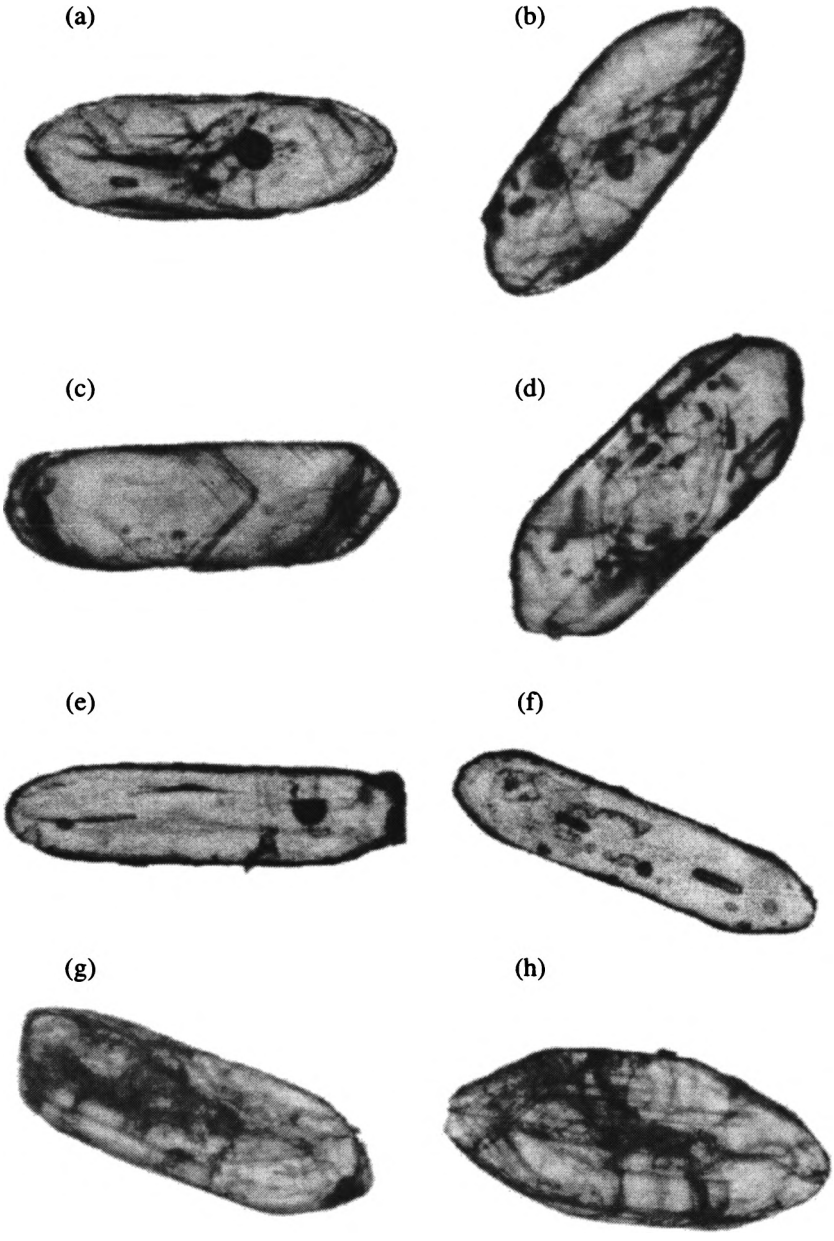


Plate II. Morphological generations of zircons from acidic metavolcanics of the Kislaya Guba Formation (sample 10548): (a, b) first generation, length 0.25–0.30 mm; (c, d) second generation, length 0.25–0.35 mm; (e, f) third generation, length 0.25 mm; (g) fourth generation, length 0.3 mm; (h) fifth generation, length 0.25 mm

mineral inclusions. The second generation of prismatic zircon crystals has well-developed facets (Plate IIc, IId, point 3 in Fig. 7 and Table 2). These crystals are transparent, with brownish tint and glassy luster. They are 0.25–0.35 × 0.075–0.100 mm in size (elongation coefficient 3–4), displaying fine zoning (7–8 zones) observed in immersion liquid, with two–three central zones that are separated from others by a more distinct dark boundary. In addition, there are visible fissures with haziness and dark films along them. The third generation is also represented by prismatic crystals (Plate IIe, IIf, point 4 in Fig. 7 and Table 2). These are transparent, with a brownish tint, insignificant haziness, and not numerous fissures. The average size of crystals is 0.25 × 0.05 mm, and their elongation coefficient varies from 4 to 5. In immersion, these zircons show the presence of rare mineral inclusions and slight transverse fissures. The fourth generation includes semitransparent prismatic crystals of the zircon type with smoothed apexes and edges (Plate IIg, point 5 in Fig. 7 and Table 2). The crystals are pinkish lilac in coloration, having glassy to greasy luster. The average size of crystals is

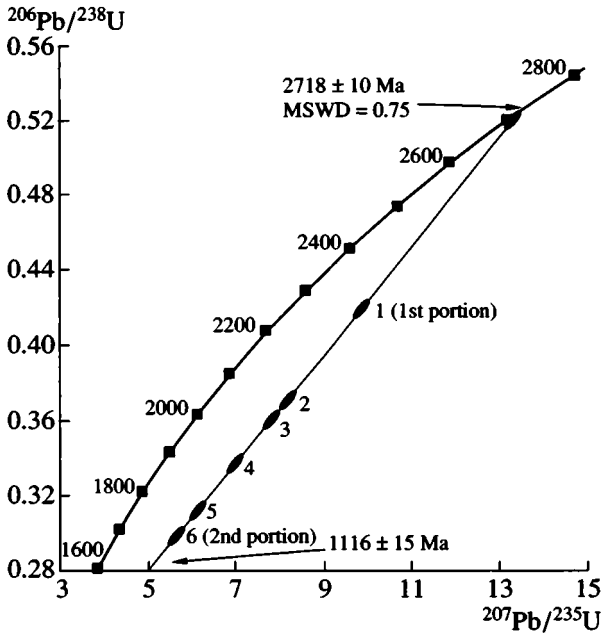


Fig. 7. The U–Pb diagram with concordia for zircons from two-mica plagiogneisses (metamorphosed rhyodacites) of the Kislaya Guba Formation.

0.30 × 0.125 mm, and elongation coefficient varies from 2.5 to 3.5. Fine vague zoning and haziness along fissures, which is responsible for irregular spotty coloration of grains, is observable in these zircons set in immersion liquid. The fifth generation includes prismatic spear-shaped crystals with smoothed edges (Plate IIh, points 1and 6 in Fig. 7 and Table 2). They are semitransparent to opaque, brown, with a cavernous surface and greasy luster. The average size of crystals is 0.25 × 0.15 mm, and elongation coefficient ranges from 1.5 to 2.5. In immersion liquid, the zircons show fine zoning (4–5 zones), numerous fissures with haziness, occasional mineral inclusions, and dark films.

The technique of two-stage acid dissolution was applied to zircons of the fifth generation to remove the metamict phase and to decrease the discordance degree. According to the accepted procedure, the weighted sample of zircons was placed first into the concentrated hydrofluoric acid and heated to the temperature of 210°C during four hours. After cooling, the dissolved phase was separated (point 6, second portion, Fig. 7, Table 2) and residue was decomposed again in the concentrated hydrofluoric acid (point 1, first portion, Fig. 7, Table 2). Owing to the acid treatment, distorted phases with high uranium concentrations were partly removed, which allowed the discordance degree to be substantially reduced.

The study method. In line with widely accepted method (Krough, 1973), samples were decomposed in the concentrated (48%) hydrofluoric acid under the temperature of 205–210°C during seven days. Fluorides of dried residue were dissolved in 3.1N HCl under the temperature of 130°C during 8–10 hours. Two weighted aliquots of 3.1N HCl solution were used to determine the Pb isotope composition and Pb and U concentrations using the isotope dilution method with the mixed $^{208}Pb + ^{235}U$ spike. The ion chromatography was used to extract Pb and U for isotopic analysis. In the blank run, laboratory contamination was below 0.2 ng for Pb and 0.04 ng for U. The U and Pb concentrations were determined using the isotope dilution method and seven-channel mass-spectrometer Finnigan-MAT-262 (RPQ) that worked in a static regime of collectors. Measurement error of ion counter used for Pb isotope analysis was ~0.025%, and silica gel was used as the ion emitter. The U and Pb concentrations are determined with uncertainty of ±0.5%. All the isotopic ratios are corrected for mass discrimination of 0.12 ± 0.04% based on parallel analysis of standards SRM-981 and SRM-982. The uncertainty of ~0.5% for U–Pb ratios is determined by statistic analysis of parallel measurement results for standard IGFM-87. Coordinates of data point and isochron parameters are calculated using the program of Ludwig (1999), and the accepted decay constants of uranium (Steiger and Jäger, 1977) are used in age calculations. All the errors are determined at 2σ level. Correction for common leads is done according to model of Stacey and Kramers (1975).

Results of U–Pb dating are presented in Table 2 and illustrated in Fig. 7. Discordia for six data points has the upper intercept with concordia at 2718 ± 10 Ma, MSWD = 0.75. The calculated value determines the minimal age of the Kislaya Guba Formation accumulation, because we analyzed acidic volcanics crowning its section. The lower intercept with concordia at 1116 ± 15 Ma reflects a partial disturbance of the U–Pb system in zircons during the Middle Riphean corresponding to the formation time of new supercontinent Rodinia during the Grenville orogeny (Hoffman, 1991; Powell *et al.*, 1993; Weil *et al.*, 1998), a fragment of which is the Baltia lithospheric plate with the Baltic shield (Baluev and Moralev, 2001; Buchman *et al.*, 2001). In the northeastern part of the Baltic shield, the Middle Riphean corresponded to the opening time of the Belomorian and Barents Sea rift systems (Dmitrovskaya *et al.*, 1997; Baluev *et al.*, 2000) filled in with terrigenous sediments and intruded by dolerite dykes (Gorbatschev *et al.*, 1987).

Thus, the available geochronological dates specify the formation period of the Terskii–Allarechensk greenstone belt, rocks of which should be referred to the Upper Lopian (*Resolution...*, 2001). The accumulation period of volcanics constituting the upper part of the Kislaya Guba Formation and the Arvarench Formation lasted approximately 10 million years.

It should be noted that the Terskii–Allarechensk greenstone belt substantially differs in age and lithology from the Kolmozero–Voron'e belt, another similar structure of the Kola Peninsula, the minimal age of

Table 2. U–Pb Isotopic data for zircons from two-mica plagiogneiss (metamorphosed dacite) of the Kislaya Guba Formation (Sample 10548)

Sample	Weighted sample, mg	Content, ppm		Pb isotope composition*			Isotopic ratios and age, Ma			Rho
		Pb	U	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{206}Pb/^{208}Pb$	$^{207}Pb/^{235}Pb$	$^{206}Pb/^{238}Pb$	$^{207}Pb/^{206}Pb$	
1 (1st portion)	0.70	51.4	113.1	4167	6.6099	9.5657	9.8643	0.41910	2325	0.91
2	0.45	148.0	372.5	2860	6.1827	8.9145	8.1698	0.37062	2427	0.91
3	0.55	94.7	229.1	2990	6.0932	7.9164	7.8204	0.36061	2455	0.94
4	0.50	69.8	183.0	1870	6.5396	6.8292	7.0190	0.33803	2300	0.86
5	0.35	83.6	244.0	1490	6.5981	8.9292	6.1415	0.31181	2262	0.86
6 (2nd portion)	0.70	66.1	203.8	3934	6.6021	9.5193	5.6543	0.29872	2325	0.89

Note: Asterisk designates data corrected for laboratory contamination by 0.08 ng Pb and 0.04 ng U, and for mass discrimination of 0.12 ± 0.04%. Two asterisks designate data corrected for common leads according to model of Stacey and Kramers (1975); (Rho) correlation coefficient.

which is 2828 ± 8 Ma based on results of dating quartz porphyries that intrude the Polmostundra Formation (Kudryashov *et al.*, 2000). Consequently, formation periods of two greenstone belts under consideration are separated by the time interval of almost 100 million years. Besides the older age, the Kolmozero–Voron'e greenstone belt hosts iron formations and differs from the Terskii–Allarechensk belt in a higher proportion of sedimentary rocks (Belolipetskii *et al.*, 1980).

Thus, it can be postulated that the Terskii–Allarechensk greenstone belt can be included into a group of the so-called young greenstone belts formed 2.85 to 2.70 Ga ago (Kozhevnikov, 2000). Accordingly, it is most similar to greenstone belts of the Canadian shield, e.g., to the Abitibi belt of the Superior Craton and Anialik belt of the Slave Craton (*Greenstone Belts*, 1997).

CONCLUSIONS

(1) The Kislaya Guba Formation of the Near-Imandra structure of the Terskii–Allarechensk greenstone belt is characterized. The formation base is represented by an intricate basal horizon approximately 300 m thick composed of several polymictic conglomerate bodies 1.5 to 40 m thick, which are separated by interbeds of amphibole and biotite–amphibole plagioschists.

(2) The formation consists of the lower, middle, and upper parts united by lithology in two large rhythms. The lower incomplete rhythm approximately 1000 m thick corresponds to the lower part of the formation and is composed of alternating biotite–amphibole to biotite plagioschists and amphibolites. The upper rhythm unites the middle and upper parts of the formation up to 2000 m thick in total. It is most complete and consists of amphibolites and amphibole, biotite–amphibole, biotite, and two-mica plagioschists successively replacing each other upward the section. The studied formation section approximately 3000 m thick and is proposed to be the unit stratotype.

(3) The minimal age of acidic metavolcanics crowning the Kislaya Guba Formation is 2718 ± 10 Ma according to results obtained. The lower age limit for the formation can be estimated only tentatively. The U–Pb age of granites from conglomerates corresponding to its basal part is 2807 Ma. The time span between the formation periods of the Voche-Lambina succession and Kislaya Guba Formation remains unknown however. Therefore, further geochronological study of volcanics from the lower part of the formation is needed to estimate the period of volcanic activity.

ACKNOWLEDGMENTS

We are grateful to Academician M.A. Semikhatov (Geological Institute, Russian Academy of Sciences) for a thorough review of the manuscript and constructive criticism, which helped to substantially improve the final version, to L.I. Koval' for extraction of accessory minerals from rocks, and to L.M. Fedorova for photographing zircons in immersion liquid. This work was supported by the Russian Foundation for Basic Research, project nos. 00-05-72032 and 01-05-64671.

Reviewers M.A. Semikhatov and A.B. Vrevskii

REFERENCES

1. A. S. Baluev and V. M. Moralev, "Structural Control and Geodynamic Settings of Intraplate Magmatism in the East European Platform," Izv. Vyssh. Uchebn. Zaved., Geol. Razved., No. 1, 13–30 (2001).
2. A. S. Baluev, V. M. Moralev, M. Z. Glukhovskii, *et al.*, "Tectonic Evolution and Magmatism of the Belomorian Rift System," Geotektonika, **34** (5), 30–43 (2000) [Geotectonics, **34**, 367–379 (2000)].
3. A. P. Belolipetskii, V. G. Gaskel'berg, E. S. Antonyuk, *et al.*, *Geology and Geochemistry of Early Precambrian Metamorphic Complexes of the Kola Peninsula* (Nauka, Leningrad (1980) [in Russian].

4. Yu. B. Bogdanov, A. S. Voinov, and B. A. Yudin, "Conglomerates from the Lake Voche-Lambina Area (Kola Peninsula)," Vestn. Leningr. Univ., Ser. Geol. Geogr. **4** (24), 46–51 (1976).
5. K. L. Buchan, R. E. Ernst, M. A. Hamilton, *et al.*, "Rodinia: the Evidence from Integrated Paleomagnetism and U–Pb Geochronology," Precambrian Res. **110**, 9–32 (2001).
6. Yu. E. Dmitrovskaya, N. A. Kagarmanyan, and T. N. Kheraskova, "Riphean Aulacogens of the East European Platform as a Fragment of the Late Precambrian Rift System of the World" in *Proceedings of the International Meeting: Precambrian of North Eurasia, April, 1997, St. Petersburg* (IGGD RAN, St. Petersburg, 1997), p. 30 [in Russian].
7. M. A. Gilyarova, *Precambrian Stratigraphy and Structures of Karelia and the Kola Peninsula* (Leningr. Gos. Univ., Leningrad, 1972) [in Russian].
8. R. Gorbatschev, A. Lindh, and Z. Solyom, "Mafic Dyke Swarms of the Baltic Shield," Spec. Pap. Geol. Ass. Can., No. 34, pp. 361–372 (1987),.
9. *Greenstone Belts, Oxford Monographs on Geology and Geophysics No. 35*, Ed. by M.D. Wit and L.D. Ashwal (Oxford Univ. Press, Oxford, 1997).
10. *Greenstone Belts in the Basement of the Russian Platform (Geology and Petrology of Volcanics)*, Ed. by S. B. Lobach-Zhuchenko (Nauka, Leningrad, 1988) [in Russian].
11. P. F. Hoffman, "Did the Breakout of Laurentia Turn Gondwanaland Inside-out?" Science **252**, 1409–1412 (1991).
12. L. Ya. Kharitonov, *Structure and Stratigraphy of Karelides in the Eastern Part of the Baltic Shield* (Nedra, Moscow, 1966) [in Russian].
13. R. V. Kislitsyn, V. V. Balahganskii, and I. Manttari, "The Age of Supracomplex from the Voche-Lambina Area, Kola Peninsula, According to U–Pb Zircon Dating," in *Proceedings of the 3rd All-Russian Meeting: General Problems of Precambrian Stratigraphy, June 13–17, Apatity* (KNTs RAN, Apatity, 2000), pp. 103–106 [in Russian].
14. V. N. Kozhevnikov, *Archean Greenstone Belts of the Karelian Craton as Accretionary Orogens* (KarNTS RAN, Petrozavodsk, 2000) [in Russian].
15. T. E. Krough, "A Low-Contamination Method for Hydrothermal Dissolution of Zircon and Extraction of U and Pb for Isotopic age Determination," Geochim. Cosmochim. Acta **37**, 485–494 (1973).
16. N. M. Kudryashev, B. V. Gavrilenko, I. V. Nikitin, *et al.*, "Geochronological Markers of the Kolmozero–Voron'e Suture Zone and Surrounding Structures (Kola Peninsula)," in *Proceedings of the 3rd All-Russian Meeting: General Problems of Precambrian Stratigraphy, June 13–17, Apatity* (KNTS RAN, Apatity, 2000), pp. 125–127 [in Russian].
17. L. N. Latyshev, "Geological Structure of Pre-Karelian Section in the Kislaya Guba—Lake Voche-Lambina Area," in *Geology and Formation History of Precambrian Structures in the Kola Peninsula* (KolFAN SSSR, Apatity, 1984), pp. 20–27 [in Russian].
18. K. R. Ludwig, "Isoplot/Excel–a Geochronological Toolkit for Microsoft Excel. Version 2.05," Spec. Publ. Berkley Geochronol. Center, No. 1a, 1–49 (1999).
19. O. I. Luneva, *Precambrian Conglomerates in the Kola Peninsula* (Nauka, Moscow, 1977) [in Russian].
20. V. P. Petrov, Z. M. Voloshina, and L. N. Latyshev, "New Data on Metamorphism of Supracrustal Rocks in the Near-Imandra Area and Their Geological Significance" in *Precambrian Geology of the Kola Peninsula* (KolFAN SSSR, Apatity, 1984), pp. 58–78 [in Russian].
21. L. N. Potrubovich, V. N. Sokolova, and E. E. Selivanovskaya, "Stratigraphy of the Terskii–Varzuga Geosynclinal Trough," in *Data on Geology and Mineral Resources of the Northwestern RSFSR*, Ed. by N. A. Volotovskaya (Nedra, Leningrad, 1967), pp. 3–19 [in Russian].
22. C. M. Powell, A. Mc, Z. X. Li, *et al.*, "Paleomagnetic Constrains on Timing of the Neoproterozoic Breakup of Rodinia and Cambrian Formation of Gondwana," Geology **21**, 889–892 (1993).
23. V. I. Pozhilenko, Yu. A. Balashov, L. F. Gannibal, *et al.*, "The Age of Endogenic Processes in the Ensk Segment of the White Sea Region," in *Proceedings of Conference on Principal Boundaries in Precambrian Geological Evolution of the Earth and Their Isotopic-Geochronological Substantiation, November 14–16, 1995, St. Petersburg* (IGGD RAN, St. Petersburg, 1995), p. 53 [in Russian].
24. V. I. Pozhilenko, T. B. Bayanova, V. A. Bogachev, *et al.*, "Relationships and Age of the Arvarench and Kuksha Formations (Mt. Arvarench, Kola Region, Baltic Shield) in *Proceedings of the 3rd All-Russian Meeting: General Problems of Precambrian Stratigraphy, June 13–17, Apatity* (KNTS RAN, Apatity, 2000), pp. 215–218 [in Russian].
25. "Resolution of the 3rd All-Russian Meeting: General Problems of Precambrian Stratigraphy," Stratigr. Geol. Korrelyatsiya **9** (3), 101–106 (2001) [Stratigr. Geol. Correlation **9**, 304–308 (2001)].
26. J. S. Stacey and J. D. Kramers, "Approximation of Terrestrial Lead Isotope Evolution by a Two-Stage Model," Earth Planet. Sci. Lett. **26**, 207–221 (1975).
27. R. H. Steiger and E. Jäger, "Subcommission on Geochronology: Convention on the Use of Decay Constants in Geo- and Cosmochronology," Earth Planet. Sci. Lett. **36**, 359–362 (1977).
28. *The Imandra–Varzuga Zone of Karelides (Geology, Geochemistry, Development History)*, Ed. by G. I. Gorbunov (Nauka, Leningrad, 1982) [in Russian].
29. *The Voche-Lambina Archean Geodynamic Polygon of the Kola Peninsula*, Ed. by F. P. Mitrofanov and V. I. Pozhilenko (KNTs AN SSSR, Apatity, 1991) [in Russian].
30. A. B. Weil, R. Van der Voo, C. McNiocaill, *et al.*, "The Proterozoic Supercontinent Rodinia: Paleomagnetically Derived Reconstructions for 1100 to 800 Ma," Earth Planet. Sci. Lett. **154**, 13–24 (1998).

Stratigraphy and Geological Correlation, Vol. 12, No. 6, 2004, pp. 553–571. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 12, No. 6, 2004, pp. 16–35.
Original Russian Text Copyright © 2004 by Veis, Fedorov, Kuzmenko, Vorob'eva, Golubkova.
English Translation Copyright © 2004 by MAIK "Nauka/Interperiodica" (Russia).

Microfossils and Riphean Stratigraphy in the North European Platform (Mezen Syneclise)

A. F. Veis†*, D. L. Fedorov, Yu. T. Kuzmenko**, N. G. Vorob'eva*, and E. Yu. Golubkova*****

** Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia*

*** Scientific Research Center "Rifei," Moscow, Russia*

**** All-Russia Research Institute of Oil Prospecting, St. Petersburg, Russia*

Received March 4, 2003

Abstract—Microphytological remains from Riphean deposits of the Mezen syneclise (Leshukon depression) have been studied in 115 core samples characterizing in detail a sedimentary section penetrated by deep borehole Srednyaya Nyafta 21. The analyzed samples are from the depth interval of 4203–2080 m that spans the Safonovo Group and underlying lithostratigraphic subdivisions. The entire succession consists of the Vashka (4203–3647 m), Peza (3647–3090 m), Leshukon (2530–2134 m), and Nyafta (2134–1837 m) formations, the lowermost one distinguished for the first time (inappropriate facies of the Dorogor and Uftyug formations have not been sampled). Microfossils representing 27 species of 23 genera have been detected in 51 samples. The Riphean stratigraphy of Mezen syneclise is analyzed based on three successive microfossil assemblages distinguished in the section. Prevailing in the Vashka assemblage are the transit Riphean morphotypes *Leiosphaeridia, Pterospermopsimorpha*, and *Nucellosphaeridium* associated with more rare *Navifusa* and *Spumosina*. In addition to forms inherited from below, the Peza assemblage includes *Chuaria, Polytrichoides*, and *Asperatofilum*. The majority of Vashka and Peza taxa, as well as acanthomorphic acritarchs *Trachyhystrichosphaera, Prolatoforma*, and associated *Pellicularia, Fabiformis, Ulophyton*, and other forms represent the composite Safonovo assemblage. The facies-ecological affinity of established microphytological assemblages is as follows: the Vashka and Peza microfossils belong to shallow-water groupings, while the Safonovo assemblage seems to be of a deeper setting. The studied microfossils enable biostratigraphic correlation of their host deposits with the Riphean stratotype of southern Urals and with other representative Riphean sections of Siberia. As a result, the Vashka Formation is attributed to the Middle Riphean, and Peza Formation together with Safonovo Group is correlated with the Upper Riphean (according to other data, the Peza Formation spans the Yurmatinian interval). The pre-Vendian succession recovered by borehole Srednyaya Nyafta 21 and bearing microphytological remains can be regarded as the Riphean reference section in the north of the East European platform.

Key words: microphytofossils, Riphean, biostratigraphy, microbiota, correlation, Mezen syneclise, East European platform.

INTRODUCTION

In last decades, microphytology of the Riphean contributed much to understanding the ancient organic world. Among the achievements, there are the detailed microphytological characterization of many representative sections of the Upper Precambrian, the agreeable interpretation of nature and biological affiliation of most Late Precambrian microfossils, which belonged to prokaryotes, eukaryotic algae, lower fungi, and protists according to the general opinion. The level of mutual understanding between adherents of morphological and paleobiological approaches to the problem is also high (*Earth's Earliest...*, 1983; *Precambrian Microfossils...*, 1989; *The Proterozoic Biosphaere...*, 1992; Butterfield *et al.*, 1994; Sergeev, 2003), although there is a certain dissonance in classification of Precambrian microfossils that complicates practice of microphytological studies.

It was expected that a deep insight into paleobiology and progress in study of organic-walled and mineralized microfossils of different age would elucidate history of Precambrian microbiota and result in elaboration of desirable biostratigraphic schemes. The expectations turned into reality to a certain extent only, and the past time showed that creation of a consistent model of Precambrian microbiota evolution meets difficulties, which are not occasional. Besides the obvious biological originality of that microbiota (*The Proterozoic Biosphaere...*, 1992; and other works) and its specific behavior in basins of that time (Veis and Petrov, 1994; Veis *et al.*, 1998a, 1998b, 1999), there are still competitive geochronological (biochronometric) and biostratigraphic approaches to model the Precambrian micro-

†Deceased.

biota evolution (Veis *et al.*, 2000, 2001; Veis and Vorob'eva, 2002).

The main principle of biochronometric approach is the priority of isotopic-geochronological dates obtained by various methods, which have been used to determine age of some indicative morphotypes or discrete microbiotas and to define the general time succession of the latter. As a consequence, the basal Riphean or terminal Paleo–Mesoproterozoic are regarded now (Knoll, 1994; Semikhatov, 1995; Knoll and Sergeev, 1995; Xiao *et al.*, 1997; Javaux *et al.*, 2001; Sergeev, 2003) as the appearance levels of most large and/or complex morphotypes (giant *Chuaria*, acanthomorphic acritarchs, lophostriated *Valeria*, wide septate and aseptate filamentous forms, branching thalluses, morphologically differentiated *Elatera, Eosolena*, etc.), although formerly they have been considered as indicators of the cardinal pre-Late Riphean transformation of microbiota (the so-called Neoproterozoic "revolution").

Adherents of the fundamentally different biostratigraphic approach to the Riphean microbiota evolution are sure that the appearance time of particular morphotypes should be defined based on their positions in most representative successions of Riphean microbiotas, first of all, in those, which are well substantiated for the Riphean stratotype and hypostratotype located in the southern Urals and Uchur–Maya region of Siberia. The isotopic-geochronological, chemostratigraphic, and any other data are regarded in this case as supplementary ones. According to available observations (Veis *et al.*, 1990; 1998a, 2000, 2003; Veis and Vorob'eva, 2002; Mikhailova and Podkovyrov, 1992; Sergeev, 1992, 2003), the remarkable morphotypes listed above do not occur in Lower–Middle Riphean interval of Uralian and Siberian sections but appear either close to the boundary that separates Middle and Upper Riphean, or at different levels of the latter. In total, they represent a succession of one-type microbiotas, which are characteristic of the stratotype and some other sections.

In this work, we used the outlined biostratigraphic approach to study a new object, the Riphean section of the Mezen syneclise in the north of the East European platform (Fig. 1), where microphytological remains are studied in detail for the first time. In earlier works published over 20 years ago (Rudavskaya *et al.*, 1977; Konopleva and Fanderflit, 1979; *The Upper Precambrian...*, 1986), there was only a brief information about sporadic occurrence of simple acritarchs and filamentous microfossils at several levels of a few borehole sections, which have been studied at that time. Additional data on some of the levels were obtained not long ago (Sivertseva, 1993; Golubkova, 2002). We studied over a hundred of samples quite regularly characterizing the Riphean interval of the deep Srednyaya Nyafta borehole section 21 (Fig. 1) drilled in 2001. In our study, we referred to the stratigraphic scheme of Riphean deposits in the Mezen syneclise, which was authorized at the Conference on Unification of Upper Precambrian Stratigraphic Schemes for the North European Region of the USSR, Syktyvkar, 1982 (*The Upper Precambrian...*, 1986; *Riphean and Vendian...*, 1987; Olovyanishnikov, 1998). In the course of investigation, we added new lithostratigraphic subdivisions to the scheme, which are worthy of discrimination in the aforementioned borehole section.

GEOLOGICAL BACKGROUND

Weakly altered Upper Precambrian, Paleozoic, and Mesozoic sediments of the Mezen syneclise overlie basement of the northeastern segment of the Scandinavian–Belarussian megablock that is a part of East European platform (Fig. 1). The Archean–Lower Proterozoic basement of syneclise is faulted into a series of linear blocks relatively risen or subsided, determining the disposition of contrast tectonic elements, such as the Koinas ledge, Verkhnyaya Pinega and Leshukon depressions, etc. (*Tectonics...*, 1988). Riphean rocks exposed within these tectonic structures are attributed to the Mezen–Vychegda structural-facies zone of pericratonic subsidence, where terrigenous shelf sediments accumulated (Olovyanishnikov, 1998).

We studied microfossils from Riphean deposits recovered by borehole Srednyaya Nyafta 21 in the northern Leshukon depression of the Mezen syneclise. The borehole was drilled in the northwestern flank of local Loftur–Aipa uplift situated in middle courses of the Nyafta River. In 2001, the borehole penetrated though sedimentary cover down to Riphean strata, to the depth of 4203 m. The core recovery within depth interval of 4203–1880 m was high. Above this interval, there were recovered pink quartz sandstones of the Tamitsa Formation, a subdivision of the Upper Vendian Redkino Horizon. According to known lithological and paleontological data, the Lower Vendian strata are missed from the section under consideration (Burzin and Kuzmenko, 2000).

The pre-Vendian succession recovered by borehole Srednyaya Nyafta 21 (Fig. 2) is close to that formerly described in the Mezen syneclise, although it includes some deeper Riphean horizons unexposed in other sections of the region. In general, the recovered succession can be divided in two large and several smaller sedimentary cycles, which correspond, respectively, to the groups and formations in the regional stratigraphic scheme (*The Upper Precambrian...*, 1986). The lower, incompletely recovered cycle (depth interval 4203–2530 m) includes three lithostratigraphic units (from the base upward): the Vashka Formation first distinguished in this work and overlying Peza and Dorogor formations, the latter terminating the cycle. L.S. Kossovoi formerly attributed the last two formations to the Ust-Nyafta Group (*The Upper Precambrian...*, 1986). The upper cycle (depth interval 2530–1880 m) includes the following subdivisions of different ranks: the Safonovo Group divided into the Leshukon and Nyafta

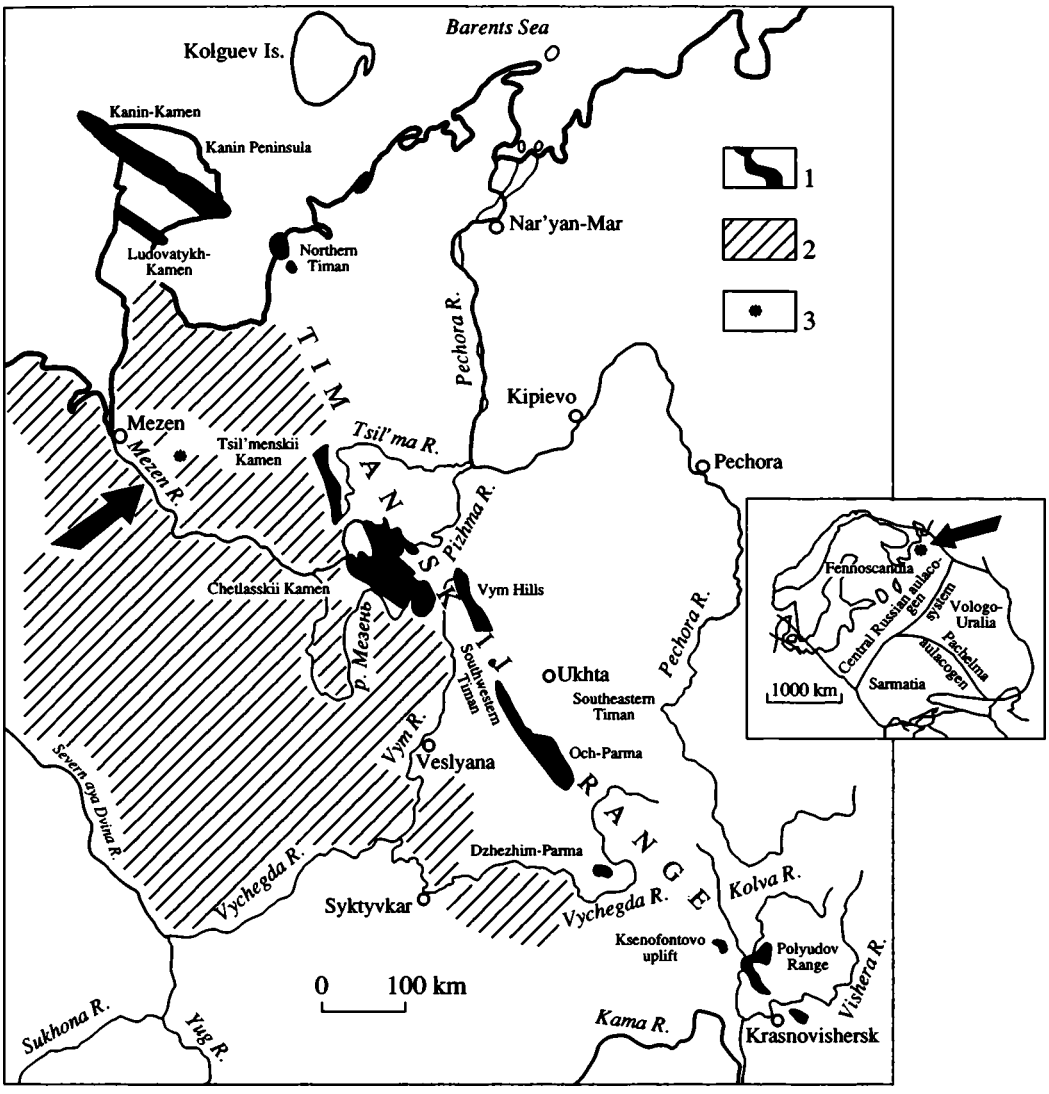


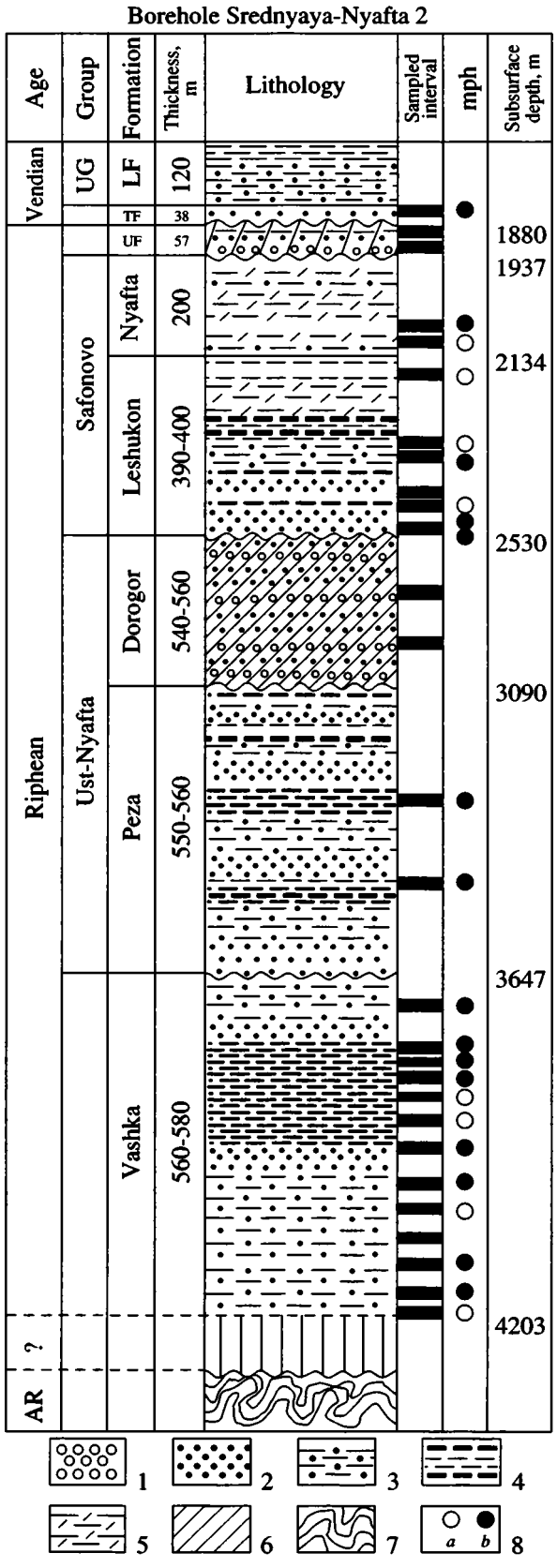
Fig. 1. Areas of exposed Upper Precambrian rocks and position of borehole Srednyaya-Nyafta 21 in the Timanskii Range–Kanin Peninsula–Polyudov Range region (inset map shows relationships between principal basement megablocks of the East European platform, which are separated by aulacogens): (1) Upper Precambrian rocks; (2) Mezen syneclise with Precambrian rocks concealed under younger sedimentary cover; (3) borehole Srednyaya-Nyafta 21.

formations and the Uftyug Formation resting on sediments of the group. All the mentioned subdivisions are briefly characterized below.

Vashka Formation. The formation is first distinguished by Yu.T. Kuzmenko who considers the depth interval of 4203–3647 m of the borehole section as the formation stratotype. The formation base has not been penetrated, although is seems to be close to the borehole bottom, where indications of weathering crust have been established. The formation is subdivided into three members.

The lower member (depth interval 4203–3980 m) is composed of sandstone, siltstone, and subordinate shale beds. Dark- to brown-gray sandstones beds with chlorite pore cement prevail near the member base, exhibit parallel to oblique bedding, and bear abundant pelitic pellets and disseminated pyrite. Above the basal interval, the sediments are intercalated with beds of dark-gray to black pyritized siltstones and shales with thin calcite veins and interlayers (0.2 cm) of oncolitic (?) limestone. Bedding planes enriched in carbonate are marked by desiccation cracks and films of organic matter. In the upper interval, there are interbeds of gray quartz–feldspar inequigranular sandstone with argillaceous–carbonate pore cement and sporadic gravely inclusions.

The middle member (depth interval 3980–3780 m) rests on presumably eroded surface of the lower member. Basal sandstone beds of the unit grade upward into shale and siltstone beds intercalated with rare interlayers of clayey limestone. Gray to greenish gray quartz-feldspar-mica sandstones with carbonate or clay



cement enclose rare fragments of chloritized basic volcanics. Greenish to dark-gray and black shales with parallel bedding are calcareous or enriched in pyrite crystals in some interlayers. Some varieties of calcareous shales enclose fragments of microbial limestone with desiccation cracks, being intercalated with cross-bedded interlayers (1–5 to 2–3 m thick) of clay limestone with abundant brown films of organic matter. Gray to dark-gray siltstones with calcareous pore or basal cement are sericitized.

The upper member (depth interval 3780–3647 m) consists, like the lower one, of alternating sandstone, siltstone, and shale beds. Gray to greenish gray sandstone of the feldspar–quartz type are cross-bedded, fine- to coarse-grained, calcareous, having clayey or quartz pore cement. Black siltstones and shales are compact, micaceous, showing admixture of sand grains. The Vashka Formation is 556 m thick in total.

Ust-Nyafta Group, Peza Formation (depth interval 3647–3090 m); the formation overlies likely the eroded surface of underlying deposits. Its lower interval is predominantly composed of gray to dark-gray micaceous arkosic sandstone fine- to medium-grained, enriched in gravely grains (2 to 3 mm across) or grading into gravelstone. The overlying black compact calcareous shales show signs of sediment sliding and presence of brown chlorite aggregates, the alteration products after glassy ash particles. Crowning the lower interval are frequently alternating laminae (up to few dozens cm thick) of dark-gray and black sales, siltstones, and sandstones.

The upper interval also consists of alternating sandy to clayey rocks. Black to brown compact micaceous shales with parallel bedding bear silty admixture, pyrite crystals, and secondary sericite. Dark-gray quartz-mica siltstones with parallel bedding are sometimes calcareous, enriched in pyrite, having clayey cement. Gray arkosic parallel- to cross-bedded sandstones are massive, fine- to coarse-grained, with inclusions of small gravely grains. Their cement of regeneration type consist of quartz and clayey material. The formation is 558 m thick in total.

The Dorogor Formation (depth interval 3090–2530 m) seems to be conformably overlying the Peza Formation. Dominant rocks of its lower part are the greenish gray and pinkish inequigranular quartz sandstones. These rocks grade into brown medium-grained massive sandstones of the middle interval, characteris-

Fig. 2. Lithostratigraphy of Riphean deposits in the Mezen syneclise, borehole Srednyaya Nyafta 21: (1) gravelstone; (2) inequigranular sandstone; (3) siltstone; (4) shale; (5) clayey limestone or dolostone; (6) red beds; (7) Early Precambrian basement rocks of the Russian plate; (8) sampling levels and samples barren of (a) or bearing (b) microphytofossils; (UF) Uftyug Formation; (TF) Tamitsa Formation; (LF) Lyamitsa Formation; (UG) Ust-Pinega Group; (mph) microphytofossils.

tic of which is admixture of coarse well-rounded grains, regeneration quartz cement, and sporadic intercalations of greenish gray siltstones and shales. The upper interval is mainly composed of brown quartzite-like sandstones with cross- and cross-wavy bedding, which enclose rare interlayers (up to 30 cm thick) of clayey gravelstones. The latter show presence of rounded fragments of basic and acid volcanic rocks. The formation is 560 m thick.

Safonovo Group, Leshukon Formation (depth interval 2530–2124 m); this formation overlies the eroded surface of the Dorogor deposits. Prevailing near the base are gray inequigranular quartz sandstones, the gravely varieties included. Above the basal interval, similar sandstones are intercalated with dark- to brown-gray shales and siltstones. Shales are parallel- and cross-bedded, showing dispersed pyrite crystals and sericite flakes. Siltstones with parallel bedding are slightly calcareous. Above them, there is ribbon intercalation of gray silty marl laminae, which are enriched in organic matter and dispersed pyrite, and almost black laminae of calcareous shales. Near the formation top, black shales rich in organic matter and pyrite crystals are intercalated with dark-gray massive feldspar-quartz siltstones and with gray fine- to medium-grained sandstones, which enclose limestone fragments with microphytoliths and oncolites. The formation is 406 m thick.

The Nyafta Formation (depth interval 2134–1938 m) conformably overlies the Leshukon deposits. In its lower part, gray to dark-gray fine-laminated, locally calcareous shales rich in dispersed organic matter are intercalated with gray fine- to medium-grained sandstones with clayey or rarer carbonate cement. Subordinate interlayers are composed of dolostone, marl, and limestone. Carbonate rocks are microcrystalline, clayey, gray to dark-gray and black in color, enriched in organic matter. In the upper interval, gray inequigranular sandstones grade upward into siltstone and shale beds with thin interlayers of dark-gray marl and gray limestone. Red sandstone and siltstone beds appear near the formation top. The formation is 186 m thick.

The Uftyug Formation (depth interval 1938–1880 m) rests on the eroded surface of underlying deposits. It is composed predominantly of brown fine- to medium-grained feldspar-quartz sandstones. Horizontal bedding of the rocks is stressed by fine silty–clayey laminae (up to 2 mm thick). The regeneration cement of sandstones is composed of quartz or carbonate. Subordinate red-brown shale, siltstone, and dolostone interlayers are enriched in dispersed organic matter and pyrite crystals. The formation is 58 m thick.

MATERIALS AND INVESTIGATION METHODS

Collection of 115 rock samples selected for microphytological analysis characterizes Riphean deposits penetrated by borehole Srednyaya Nyafta 21 in the depth interval of 4203–2080 m. Visible in the samples is fine interlamination of black, gray, and greenish shales, siltstones, and fine-grained sandstones with occasional laminae of coarse-grained sandstones and/or red-colored rock varieties. The analyzed samples, including those collected by M.B. Burzin, belong to four lithostratigraphic units of the Mezen syneclise section, namely to the Vashka (77 samples), Peza (7 samples), Leshukon (23 samples), and Nyafta (8 samples) formations. Rare to abundant microfossils have been found in 51 of 115 samples. Sampling levels in the borehole section Srednyaya Nyafta and taxonomic composition of identified microfossils are illustrated in Figs. 2 and 3. Deposits of the Dorogor and Uftyug formation barren *a priory* of microphytological remains have been excluded from consideration.

Laboratory treatment of samples was as follows. (1) Core samples (about 500 g each in average) were disintegrated first. (2) To clean disintegrated material from carbonates and other unnecessary impurities, the recent contaminants included, the material was treated in 10–20% HCl and/or KOH solutions. (3) The cleaned fraction was subjected to dissolution in concentrated HF. (4) The unsolvable residue screening through sieve with hole diameter of 15–30 μm was used to separate coarse fraction with organic remains from fine clay and organic matter. (5) Microphytological remains present in coarse fraction were picked up under binocular microscope. (6) Fine residue after sieving, being submerged into heavy liquid M-45 (specific density 2.1–2.2 g/cm^3), was divided into fractions by centrifuging.

According to analysis, most abundant and diverse microfossils are buried in sediments of Safonovo Group (in 14 and 7 samples from the Leshukon and Nyafta formations, respectively).[1] In the Vashka (25 samples) and Peza (5 samples) formations, they are less abundant. All the samples with microfossils, including those with single specimens, contain organic matter (sometimes quite abundant) forming sapropelic films. Films of this kind have not been observed in 10 samples only. Single or two–three samples lacking these films are found to belong to depth intervals 2525.7–2522.5, 3192.3–3187.9, 3734.7–3721.3, 3800–3790, 4159–4151, and 4203–4191 m. All samples from depth intervals 4043–4036, 3986–3979, 3928–3920, 3870–3864, and 3671–3520 are enriched to a variable extent in organic matter that is particularly abundant in depth intervals 2523.7–2522, 2336–2503, and 2100–2080 m.

Color index of best-preserved organic remains (light yellow to dark orange) from the depth interval 2523.7–2080 m implies that sediments of Safonovo Group have never been heated above 80–100°C. Microfossils from the Vashka and Peza formations (depth intervals 4159–3520 and 3277.8–3092 m) are colored brown with var-

[1] We consider below only those intervals of recovered core section (they are shown in Fig. 2), which yielded microfossils. Taxonomic composition of microfossils is depicted in Fig. 3, and most characteristic morphotypes are figured in Plates I–IV.

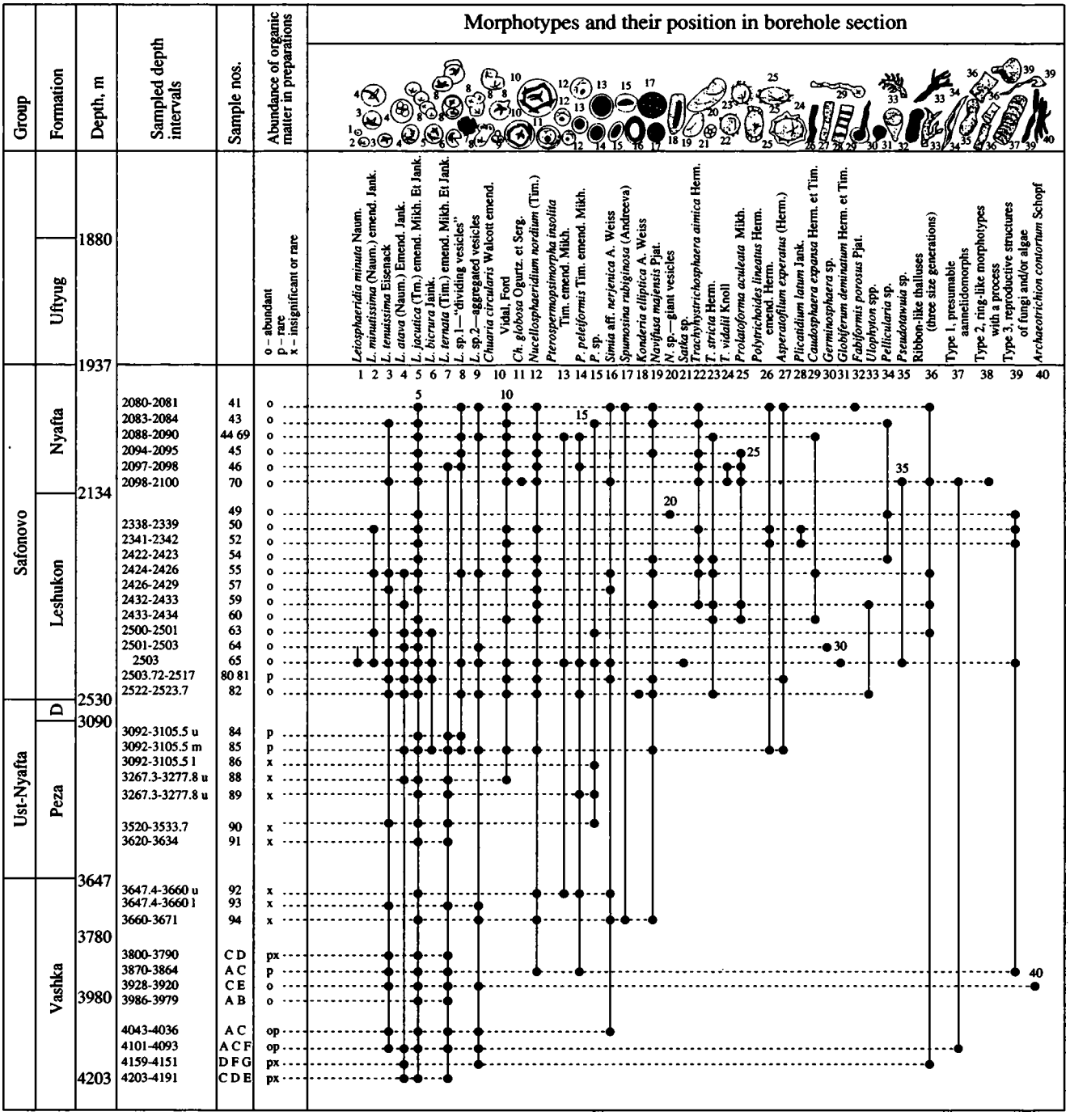


Fig. 3. Stratigraphic ranges of microfossil genera and species in Riphean deposits penetrated by borehole Srednyaya-Nyafta 21: (D) Dorogor Formation; (l) lower, (m) middle, and (u) upper levels of depth intervals sampled for microphytological analysis.

ious tints that is characteristic of organic remains heated up to 160–180°C (Hayes *et al.*, 1983). The preservation state of studied microfossils is therefore good to satisfactory. Many of acritarchs, filamentous and complex morphotypes are damaged. Classification of studied microfossils is as that used in our previous works (e.g., Veis *et al.*, 2003), slightly modified as compared to taxonomy accepted earlier (*Precambrian Microfossils...*, 1989).

MICROPHYTOLOGICAL DATA

Vashka Formation. Lower member (4203–3980 m). Microfossils have been encountered within four depth intervals: 4203–4191 (3 samples), 4159–4151 (3 samples), 4101–4093 (4 samples), and 4043–4036 m (3 samples). Prevailing in the member are *L. tenuissima* Eisenack and thickened *L. jacutica* (Tim.) emend. Mikh. et Jank. (up to 200 or less fre-

quently to 280 μm in diameter).[2] Compact *L. atava* (Naum.) emend. Jank. and *L. ternata* (Tim.) emend. Mikh. et Jank. with peripheral fracturing are less abundant and smaller in size (up to 110 μm). The smallest *L.* sp. 2 are represented by isolated or clustered vesicles. *Nucellosphaeridium nordium* (Tim.) (up to 120 μm) with inner bodies, rimmed *Simia* aff. *S. nerjenica* A. Weiss (190–200 μm), isolated and tightly interlaced fine filamentous sheaths *Archaeotrichion contortum* Schopf (sheaths 1–1.5 μm wide, thalluses up to 300 μm across), and two ribbon-like morphotypes (?thalluses) are the other microfossils characteristic of the lower Vashka member. Ones of the latter morphotypes are broad, elongated, and irregularly plicated (60–70 μm wide), while the others are narrow, ring-like coiled (thalluses 16–20 μm wide, rings 180 μm in diameter).

Middle member (3980–3780 m). Microfossils are found in 10 rock samples from the member, which characterize depth intervals 3980–3979 m (2 samples), 3928–3920 m (3 samples), 3870–3864 m (3 samples), and 3800–3790 m (2 samples). Relatively abundant are simple *Leiosphaeridia jacutica* (up to 200–220 μm), smaller *L. ternata* (100–110 μm), and accumulations of several small vesicles *L. tenuissima* (80–90 μm in dimension each). *Nucellosphaeridium nordium* and *Pterospermopsimorpha pileiformis* Tim. emend. Mikh. (140–180 μm) with internal bodies, and filamentous *Archaeotrichion contortum* (1–1.5 μm), which do not form thalluses, are less abundant. In addition, sediments of the member yield peculiar morphotypes (each 20 × 100–150 μm in size), which look like small chains of elongated bodies with rounded endings and resemble the narrowest and longest representatives of Riphean *Brevitrichoides.*

Upper member (3780–3647 m). Microfossils of the member are detected in depth intervals 3671–3660 m (1 sample) and 3660–3647 m (2 samples). In all these samples, dominants are thin-walled and thickened *Leiosphaeridia tenuissima, L. jacutica., L. ternata* (from 50–70 to 280–300 μm), accumulations of *L.* sp. 2 (90–100 μm), and *L. ternata* (up to 160 μm) with peripheral clefts. In comparison with *Leiosphaeridia* forms, *Nucellosphaeridium nordium, Pterospermopsimorpha insolita* Tim. emend. Mikh., and *P. pileiformis* (with external diameters 240, 280, and up to 320 μm, respectively) are next in abundance. Even more rare are rimmed *Simia* aff. *S. nerjenica* (240 μm), spongy *Spumosina rubiginosa* (Andreeva) (130 μm), and ellipsoidal *Navifusa majensis* Pjat. (240 × 400 μm).

Ust-Nyafta Group. Peza Formation (3647–3090 m). Microfossils of this formation are discovered in 7 sample from depth intervals 3634–3620 m (1 sample), 3533.7–3520 m (1 sample), 3277.8–3267.3 m (2 samples), 3105.5–3092 m (3 samples). Dominants of the Peza assemblage are thin-walled and thickened *Leiosphaeridia tenuissima, L. atava, L. jacutica* (up to 210 μm in diameter), and vesicles *L. bicrura* Jank. with median and *L. ternata* with peripheral clefts, including abnormally large (up to 500–740 μm) representatives of the last taxon. The smallest *Leiosphaeridia* occur in accumulations of *L.* sp. 2 or as "dividing" vesicles *L.* sp. 1; both morphotypes are up to 100 μm in diameter. Large compact sphaeromorphic *Chuaria circularis* Walcott emend. Vidal et Ford (up to 480 μm), ellipsoidal *Navifusa majensis* (200 × 320 μm), and bearing inner bodies *Nucellosphaeridium nordium* (up to 580 μm across), *Pterispermopsimorpha pileiformis* (up to 220 μm across), and *P.* sp. (up to 240 μm across) are less frequent components of the assemblage. The listed acritarchs occur in association with multiserial filamentous sheaths *Polytrichoides lineatus* Herm. emend. Herm. (some sheaths up to 4 μm wide, their aggregates up to 40 μm in size) and with tubular *Asperatofilum experatus* (Herm.) with shagreen surface (30–40 μm).

The overlying Dorogor deposits have not been analyzed.

Safonovo Group. Leshukon Formation (2530–2134 m). Microphytological remains from this formation are confined to depth intervals 25237–2522 m (1 sample), 2517–2500 m (6 samples), 2434–2422 (5 samples), and 2342–2338 m (2 samples). Most characteristic of the formation are three morphotypes of acanthomorphic acritarchs: (1) sphaeromorphic *Trachyhystrichosphaera aimika* Herm. without peripheral membrane though with cylindrical processes; (2) *T. stricta* Herm. with short spines set into filmy rim (both up to 160–450 μm); (3) ellipsoidal *Prolatoforma aculeate* Mikh. (340 × 460 μm) with bipolar positions of spines and thin membrane. Associated with these forms are very small *Leiominuscula minuta* Naum. (up to 10 μm), thin medium-sized *Leiosphaeridia tenuissima* and larger *L. jacutica* (100–150 and 280–300 μm in dimensions, respectively), vesicles *L. bicrura* (320 μm) with median cleft, *Konderia elliptica* A. Weiss with ellipsoidal inclusion (180 × 320 μm), oval *Navifusa majensis* (200 × 450 μm), giant *N.* sp. (longer axis up to 1500 μm), *Chuaria circularis* (up to 500–520 μm), platy *Satka* sp. (up to 220 μm in diameter), *Nucellosphaeridium nordium, Pterospermopsimorpha insolita, P. pileiformis* (from 260 up to 580 μm in diameter), rimmed *Simia* aff. *nerjenica* with distinct peripheral plication (up to 240 μm).

In addition, we identified relatively rare filaments *Plicatidium latum* Jank. (up to 110 μm) with fine transverse ornamentation locally preserved, multiserial *Polytrichoides lineatus* (aggregates and sheaths 40 and 2–4 μm wide, respectively), and shagreen tubular *Asperatofilum experatus* (40–50 μm). Morphotypes of a complex structure are represented by the following taxa: spheroidal *Germinosphaera* sp. with a short process (up to 200 μm, process 10–20 μm long), drop-shaped *Caudosphaera expansa* Herm. et Tim. with a very long process (vesicle up to 340 μm in diameter, process over 400 μm long), asymmetrical *Globiferum*

[2] Author names are given in this work by the first mention of a taxon.

deminatum Herm. et Tim. (120 μm), branching *Ulophyton* sp. with conical base and densely interlaced thin rami of various orders (up to 400 μm high), fusiform filmy *Pellicularia* sp. (up to 600 μm), dumbbell-like *Pseudotawuia* sp. (320–340 × 500–520 μm), and dark to light ribbon-like thalluses of three size generations (60–80, 100–120, and 140–160 μm).

Nyafta Formation. Microfossils are confined to a relatively narrow interval of the formation section (7 samples, depth range 2100–2080 m). Among them there are many acritarchs with or without filmy rim. These are *Trachyhystrichosphaera aimika, T. stricta,* and *T. vidalii* Knoll (from 160 up to 460 μm in diameter). Thin-walled and thickened *Leiosphaeridia tenuissima* and *L. jacutica* (both up to 280 μm) are the most abundant taxa, which occur in association with less frequent large dense *Chuaria circularis* (up to 750 μm), ellipsoidal *Navifusa majensis* (up to 400 × 700 μm), and vesicles with internal bodies *Nucellosphaeridium nordium, Pterospermopsimorpha pileiformis,* and *P. insolita* (up to 580 μm). Less abundant morphotypes are represented by small vesicle aggregates *Leiosphaeridia* sp. 2, "dividing" forms *L.* sp 1 (both up to 100–150 μm), and by *L. ternata* with peripheral clefts (150 μm). The other acritarchs characteristic of the Nyafta Formation are *Simia* aff. *S. nerjenica, Spumosina rubiginosa, Chuaria globosa* (up to 240 μm in diameter) are of subordinate significance.

Besides acritarchs, samples from the Nyafta Formation yielded abundant filamentous polytrichomes *Polytrichoides lineatus* (aggregates up to 40 μm across, individual sheaths 2–4 μm in size) and shagreen tubular *Asperatofilum experatus* (40–60 μm). The associated complex morphotypes are as follows: large drop-like *Caudosphaera expansa* with solitary long processes (vesicles up to 150 μm in diameter, processes up to 250 μm long), elongated spongy *Fabiformis porosus* Pjat. (160 × 320 and 220 × 600 μm), fabiform *Pseudotawuia* sp. with inclusions in swollen parts (320 × 500 μm), ribbon-like thalluses of two size generations (80 to 100–120 μm wide), ramified *Ulophyton* sp. (over 100 μm high), fusiform filmy *Pellicularia* sp. (up to 900 μm), cuticular bag-shaped bodies with distinct transverse homonomous segmentation like in Riphean annelidomorphs *Parmia* Gnil. (200 × 700 μm), and elongated asymmetric forms solitary or coupled by broadened terminations (up to 1000 μm long), comparable with weakly dissected *Vendomyces* Burzin.

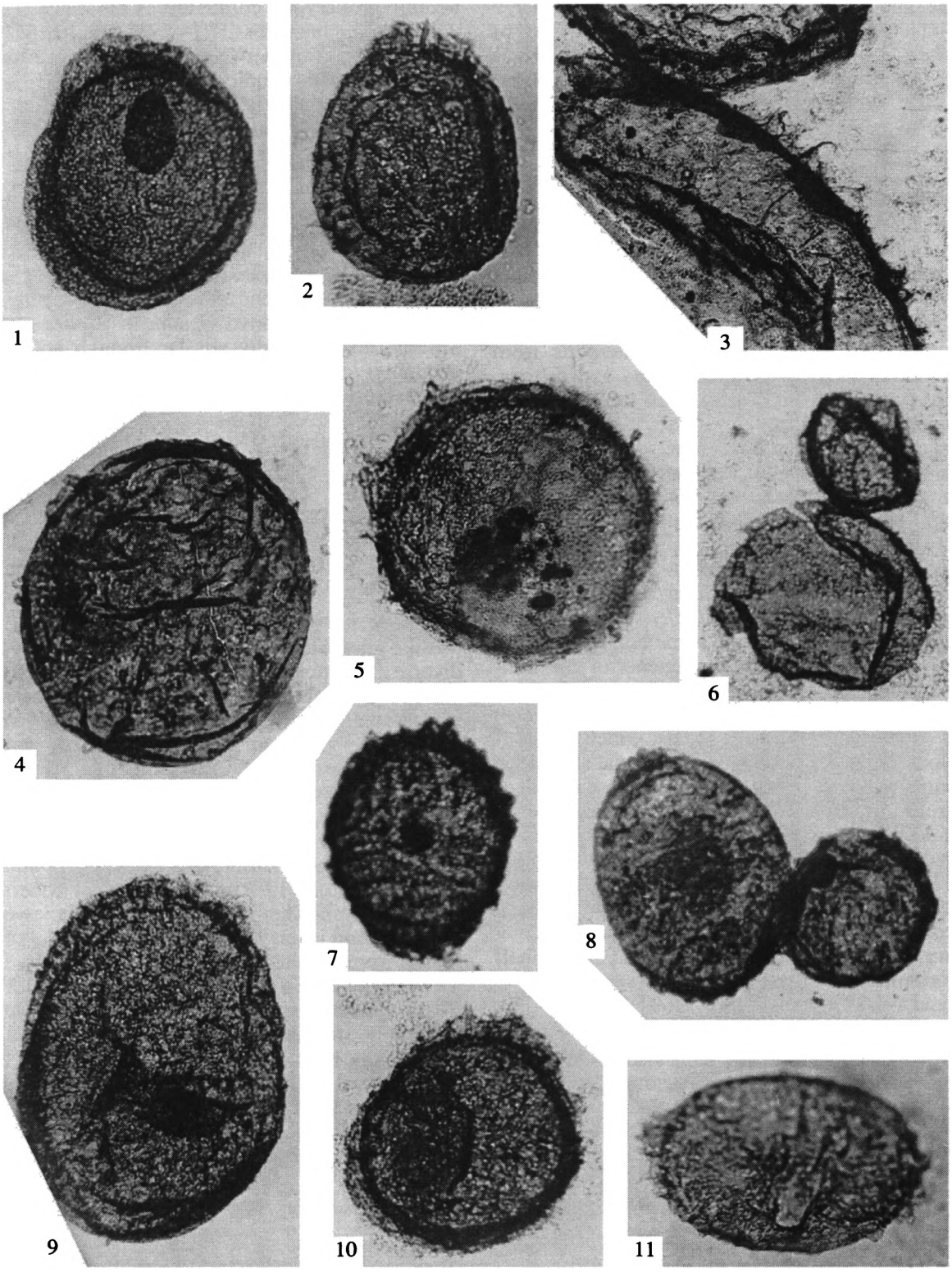
Data presented above show that microfossil assemblages from Leshukon and Nyafta formation are very close to each other in terms of species and especially generic compositions. Insignificant distinctions between them seem to be related to local taphonomic factors and cannot be organized in vertical succession. The taxonomic uniformity of the Leshukon and Nyafta assemblages, which include abundant and diverse microfossils, including many complex morphotypes in common, differs them from much less diverse assemblages characteristic of underlying Peza and, especially, Vashka assemblages impoverished in or lacking forms of complex morphology. It is impossible to explain this key distinction between microbiotas from the lower and upper stratigraphic levels from the taphonomic standpoint. Let us consider therefore the established succession of microbiotas in the facies-ecologic and biostratigraphic aspects based on experience of studying microfossils in the most complete Riphean sections of the southern Urals and Siberia.

DISCUSSION AND CONCLUSIONS

Facies-ecologic interpretation of studied microbiotas. The established taxonomic compositions of four discrete microbiotas from Riphean deposits of the Mezen syneclise open a possibility to understand influence of paleoecologic factors on the specific features of the vertical succession of microbial assemblages. Main peculiarities in lateral distribution of ancient microorganisms and their communities were established based on microfossil assemblages from well-studied reference sections of the Riphean in Siberia (Veis and Petrov, 1994; and other works). As is established, the Riphean epicontinental shelf seas were populated by four facial-ecological groupings of microorganisms (deep-water, medium-deep or "optimal", transitional, and shallow-water) different in taxonomic composition and regularly replacing one another along the basin profile. In terms of composition, the shallow-water and medium-deep or "optimal" groupings were most contrasting. The former populated mostly the upper subtidal and some intertidal settings and consisted of relatively simple and small phytoplanktonic microorganisms in the zone of siliciclastic sedimentation or of mat-forming prokaryotes on carbonate platforms. The "optimal" grouping of lower subtidal settings of the proximal and some distal shelf areas of carbonate and silici-

Plate I. Late Riphean microfossils from the Mezen syneclise, Russian plate (all the specimens are stored at the Geological Institute, Russian Academy of Sciences, Moscow).
(1, 2, 8–11) *Prolatoforma aculeata* Mikh.: (1) specimen no. 2433–601, (2) specimen no. 2098–461, (8) specimen no. 2094–452, (9) two aggregated vesicles, specimen no. 2433–602, (10) specimen no. 2433–591, (11) specimen no. 2098–463; (3, 6) small *Leiosphaeridia*–like vesicle (above) associated with large spheroidal form ex gr. *Cymatiosphaeroides* (below) that has many fine curved processes seen in enlarged fragment (3), specimen no. 2094–451; (4) *Trachyhystrichosphaera aimika* Herm., specimen no. 2338–501; (5) *T. stricta* Herm., specimen no. 2424–551; (7) *T. vidalii* Knoll, specimen no. 2098–462.
Stratigraphic confinement: (1, 4, 5, 9, 10) Leshukon Formation, (2, 3, 6–8, 11) Nyafta Formation, Safonovo Group. Depth interval in borehole Srednyaya Nyafta 21: (1, 9) 2434–2433 m, (10) 2433–2432 m, (5) 2426–2424 m, (4) 2339–2338 m, (2, 7, 11) 2100–2098 m, (3, 6, 8) 2095–2094 m. Magnification: (1) ×450, (2–4) ×400, (5, 10, 11) ×200, (6) ×100, (7–9) ×150.

Plate I



clastic sedimentation consisted of planktonic and predominant benthic eukaryotes represented by large morphotypes of a complex structure. In deepest areas of distal shelf, composition of Riphean microbiotas changed significantly, and they were represented mostly by microorganisms decomposing the organic matter. The data obtained showed that the basin depth, hydrodynamic activity, and habitat environments of microbiotas during the transgressive–regressive trends of the basin evolution were the main among recognizable factors, which controlled the lateral distribution of microorganisms in the Riphean sea basins (see for details Petrov and Veis, 1995; Veis *et al.*, 1998a, 1998b, 1999).

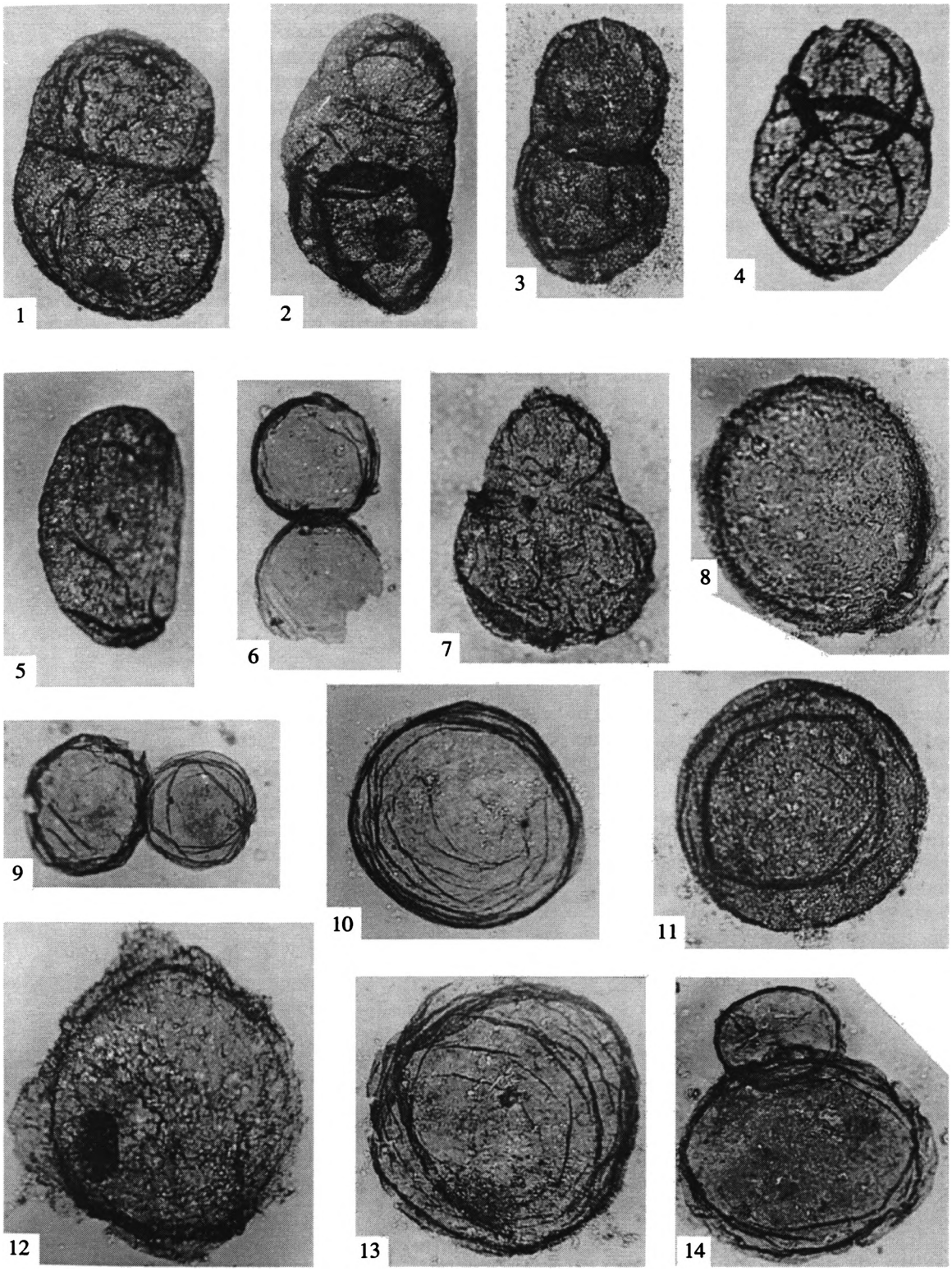
The comparison of most diverse Leshukon and Nyafta microbiotas with possible counterparts from Riphean deposits of the southern Urals and Siberia, which are comprehensively studied in the facies-ecologic aspect, suggest that microfossil assemblages of the Safonovo Group in total belong to the "optimal" (medium-deep) groupings of Riphean microorganisms. As argument in favor of this assumption, we should mention that both microbiotas from the Mezen syneclise include the giant *Chuaria*, rimmed *Simia*, acanthomorphic *Trachyhystrichosphaera* and *Prolatoforma*, sheaths *Polytrichoides, Plicatidium*, and forms of a complex morphology, such as *Ulophyton, Fabiformis, Pseudotawuia, Pellicularia*, and some others. All these morphotypes are distinctive components of the indicated grouping. In the Riphean sea basins of southern Urals and Siberia, comparable assemblages of microfossils were buried only in sediments, which accumulated in lower subtidal settings and proximal shelf zone of epicontinental seas below storm wave base (depth of few dozens meters). Some representatives of the medium-deep grouping of Riphean microorganisms penetrated only by occasion into the shallower upper subtidal zone usually occupied by shallow-water and/or transitional groupings. Their penetration strictly depended therewith on availability of specific quiet environments in semi-isolated settings of inner shelf zone or on suitable contrast forms of the sea-floor relief (Petrov and Veis, 1995; Veis *et al.*, 2001).

The assumed facies-ecologic affinity of the Leshukon and Nyafta microbiotas is also evident from abundance and diversity of their acritarchs, which are regarded as remains of eukaryotic phytoplankton. In contrast to acritarchs, filamentous mat-forming morphotypes considered usually as representatives of benthic prokaryotic communities are much less abundant among microfossils from the Safonovo Group. Such a proportion between morphotypes of two kinds can be regarded as indicative of a relatively deep accumulation setting of their host deposits. In addition, the paucity of filamentous forms and extremely low abundance of associated colonial coccoidal microfossils may imply that shallow shelf areas, where they commonly dwelt or had been buried, might be reduced or even absent in the Safonovo basin. The idea that this basin was relatively deep is also consistent with the first-priority abundance of nearly all complex morphotypes and high concentration of kerogen detritus in both formations of Safonovo Group. In Riphean basins of Siberia, taxonomically similar (though not identical) groupings of microorganisms were characteristic of deepest settings of their "optimal" habitat zone that was usually far away from the coastline, extending down to the distal shelf. It would be correct to remember therewith that a high abundance of thin-walled taxa in Safonovo microbiota and evidence of bacterial destruction they reveal mean not only the calm-water habitat and taphonomic environments, but also a specific character of the Leshukon and Nyafta basins as compared to Riphean epicontinental sea basins of Siberia.

The facies-ecologic interpretation of older Peza and Vashka microbiotas is not so easy because they are less diverse. The most remarkable morphotypes from Peza Formation, such as *Chuaria*, "dividing" vesicles and monstrous *Asperatofilum, Polytrichoides, Navifusa, Leiosphaeridia ternata*, and *L. bicrura*, were most characteristic of transitional grouping that populated relatively shallow settings in the lower subtidal zone. At the same time, the first and three last taxa not only occur, but also determine a general aspect of the deepest groupings of microorganisms, which populated the distal shelf zone in Riphean basins of Siberia (Veis *et al.*, 1998b). The same duality in facies-ecologic interpretation is unavoidable by examination of microfossils from the Vashka Formation (especially from its upper member). In addition to *L. ternata* and *Navifusa* forms occurring in the Peza formation, sediments of the Vashka Formation yield *Spumosina* and *Simia*. In the Miroedikha basin of Siberia, *Spumosina* forms were most typical of seaward areas of the distal shelf, whereas *Simia* migrated in contrast toward the coastline up to the proximal limitation of the lower subtidal zone.

Plate II. Late Riphean microfossils from the Mezen syneclise, Russian plate (all the specimens are stored at the Geological Institute, Russian Academy of Sciences, Moscow).
(1–4, 7) "dividing vesicles" (monstrous forms) *Leiosphaeridia* sp. 1: (1) specimen no. 2089–690, (2) specimen no. 2098–464, (3) specimen no. 2088–440, (4) specimen no. 2080–410, (7) specimen no. 2083–430; (5) *Navifusa majensis* Pjat., specimen no. 2080–411; (6, 9, 14) aggregated vesicles *Leiosphaeridia* sp. 2: (6) specimen no. 2503–651, 9) specimen no. 2503–652, 14) specimen no. 2503–653; (8, 11, 12) *Simia nerjenica* A. Weiss: (8) specimen no. 2080–412, (11) specimen no. 2080–413, (12) specimen no. 2098–466; (10, 13) *Leiosphaeridia tenuissima* Eisenack: (10) specimen no. 2098–465, (13) specimen no. 2098–467.
Stratigraphic confinement: (6, 9, 14) Leshukon Formation, (1–5, 7, 8, 10–13) Nyafta Formation, Safonovo Group. Depth interval in borehole Srednyaya Nyafta 21: (6, 9, 14) 2517–2503 m, (2, 10, 12, 13) 2100–2098 m, (1) 2090–2088 m, (3) 2099–2088 m, (7) 2085–2083 m, (4, 5, 8, 11) 2081–2080 m. Magnification: (1, 2, 4, 6, 7, 13, 14) ×150, (3, 8, 10, 12) ×200, (5, 9) ×100, (11) ×250.

Plate II



It is hardly possible to find undisputable solution of above dilemma based on limited data from a single borehole. Nevertheless, concentration of organic matter in most samples from the Vashka and Peza formations is much lower than in overlying Leshukon and Nyafta deposits of relatively deep-water setting. In view of general sedimentological trends established based on direct observations of Riphean marine sediments in central Siberia, the indicated distinction in the organic matter content can be regarded as indirect argument in favor of relatively shallow-water environments during the accumulation time of the Vashka and Peza formations.

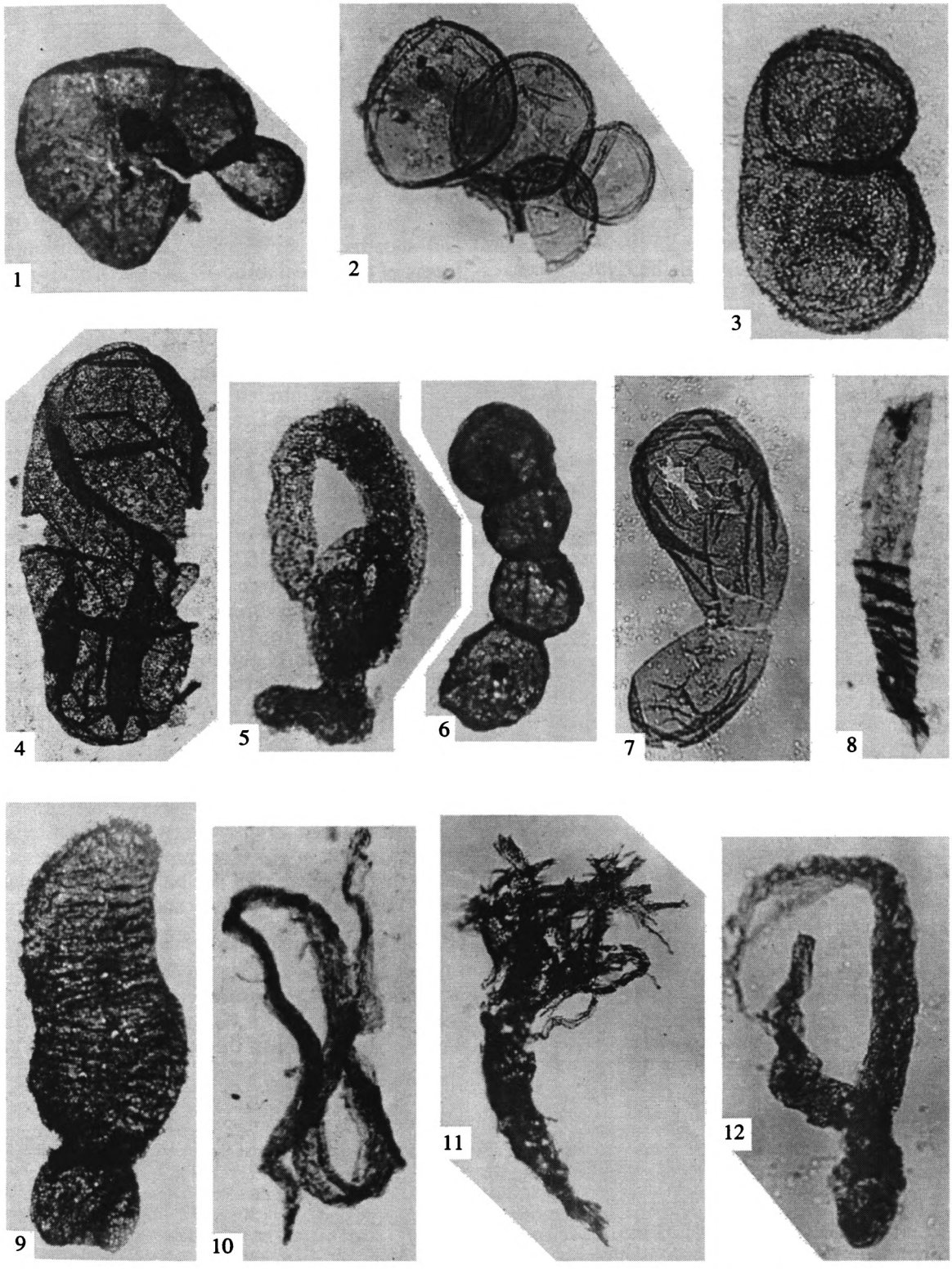
Thus, it is possible to state the following. First, accumulation environments inferable for Riphean deposits of the Mezen syneclise based on microphytological data are consistent with implications from independent lithologic and tectonic observations of sedimentary cover in the Mezen–Vychegda structural-facies zone. According to these observations, mostly siliciclastic Riphean succession of this zone accumulated in the course of several transgressive–regressive cycles within a shallow sea basin that was a part of subsiding marginal shelf zone of ancient platform (Olovyanishnikov, 1998). Second, the inferable environmental changes in Riphean basin of the Mezen syneclise could be responsible just partly for the established vertical trend of taxonomic innovations in microbiota composition, the successive appearance of very large and/or complex morphotypes included. The other possible explanation of the above vertical trend could be related with irreversible evolution of ancient microworld, which determines biostratigraphic potential of newly appearing taxa.

Biostratigraphic analysis of studied microfossils. Considering stratigraphic significance of microfossils from Riphean deposits of the Mezen syneclise, we paid main attention to regional succession of their discrete assemblages separated by distinct levels, which mark changes in taxonomic composition, size ranges and/or morphological complexity of taxa present in microbiotas. In terms of chronostratigraphic approach to Riphean successions, age of microfossil assemblages should be determined based on their correlation with most similar (homotaxial) microbiotas (assemblages) in the "standard" microfossil succession established for the Riphean stratotype in southern Urals. Supplementary data on microbiotas from other regions can be involved only if their regional and standard successions are properly correlated by means of microphytological analysis (Veis and Vorob'eva, 2002; Veis *et al.*, 2001, 2003).

According to all known data, in the Riphean stratotype of Bashkirian meganticlinorium there are four microbiotas unequally representative, having different stratigraphic ranges, and important for interregional biostratigraphic correlations. These are a single Lower–Middle Riphean (Burzyanian–Yurmatinian) and three Upper Riphean (Karatavian) microbiotas, the latter known as the Nugush (Kabakovo), Bederysh (Muldakaevo), and lower Inzer (Shishenyak) microfossil assemblages (*Stratotype of the Riphean...*, 1982; *Precambrian Microfossils...*, 1989; Veis *et al.*, 1990, 2003). Below, we denote them by indices R_{1-2}, R_3^1, R_3^2, and R_3^3. The pre-Karatavian (presumably post-Yurmatinian) Tyul'ma and Kuzha microbiotas are excluded from consideration because of their ambiguous position in the Riphean stratotype. The youngest in the Uralian succession is the Uk (Kudash) assemblage of microfossils from the stratotype, but its biostratigraphic significance was doubted recently (Veis *et al.*, 2003). According to biostratigraphic criteria, four reference microbiotas of southern Urals, which are mentioned above, are correlative with Riphean microbiotas of central Siberia. Their analogs are the Uchur-Aimchan (R_{1-2}), Kerpyl (R_3^1), and Lakhanda-Ui (R_3^2) microbiotas of the Uchur–Maya region, and the Bezymyannyi (R_3^1), Derevnya (R_3^2), and Miroedikha (R_3^3) microbiotas of the Turukhansk uplift (Veis and Vorob'eva, 2002). With due account for microphytological data on the other well-studied regional section, microbiota of the Svanbergfjellet Formation, the Akademikerbreen Group of northeastern Spitsbergen, which has been regarded as illustrating an important step in evolution of ancient microworld (Butterfield *et al.*, 1994; Butterfield and Rainbird, 1998), is most likely crowning the general

Plate III. Late Riphean microfossils from the Mezen syneclise, Russian plate (all the specimens are stored at the Geological Institute, Russian Academy of Sciences, Moscow).
(1, 3, 7) "dividing vesicles" (monstrous forms) *Leiosphaeridia* sp. 1.: (1) specimen no. 2424–552, (3) specimen no. 2433–603, (7) specimen no. 2089–691; (2, 6) aggregated vesicles *Leiosphaeridia* sp. 2: (2) specimen no. 2500–630, (6) specimen no. 2424–553; (4) giant *Navifusa* sp., specimen no. 2094–453; (5) regularly contorted thalluses (type 2, ring-like structures with a process), specimen no. 2098–468; (8) *Plicatidium latum* Jank., contorted part of the remains simulate presence of transverse walls, specimen no. 2338–502; (9) large ellipsoidal morphotype with regular transverse (? homonomous) segmentation and spherical body attached to one of poles (type 1, presumable "annelidomorphs"), specimen no. 2098–469; (10) small vesicle with a long process (type 3, possible reproductive structures of ancient algae and/or fungi), specimen no. 2338–503; (11, 12) *Ulophyton* spp.: (11) specimen no. 2522–820, (12) specimen no. 2522–821.
Stratigraphic confinement: (1–3, 6, 8, 10–12) Leshukon Formation, (4, 5, 7, 9) Nyafta Formation, Safonovo Group. Depth interval in borehole Srednyaya Nyafta 21: (11, 12) 2523–2522 m, (2) 2501–2500 m, (8, 10) 2339–2338 m, (3) 2434–2433 m, (1, 6) 2426–2424 m, (8) 2339–2338 m, (5, 9) 2100–2089 m, (4) 2095–2094 m, (7) 2089–2090 m. Magnification: (1, 6, 8) ×100, (2, 3, 5, 7, 12) ×200, (4, 9) ×60, (10) ×600, (11) ×150.

Plate III



succession of South Uralian and correlative Siberian microbiotas. Here its index is R_3^4.

In the studied Riphean section of Mezen syneclise, microfossils have been detected at 17 microphytological levels. Levels 1 to 9 are in the Vashka Formation (depth intervals 4203–4119, 4159–4151, 4101–4093, 4043–4036, 3886–3979, 3928–3920, 3870–3864, 3800–3790, 3671–3647 m), levels 10 to 13 in the Peza Formation (depth intervals 3634–3620, 3533–3520, 3277–3267 and 3105–3092 m), levels 14 to 16 in the Leshukon Formation (depth ranges 2529–2500, 2434–2420, 2342–2336 m), and level 17 in the Nyafta Formation (depth range 2100–2080 m). According to appearance levels of indicative morphotypes, all the identified microfossils represent three distinctive assemblages. The lowermost Vashka assemblage (5 genera, 8 species) is lacking remarkable taxa; the next Peza assemblage (7 genera, 10 species) is of a low diversity; and the upper representative Safonovo assemblage includes diverse microfossils from the Leshukon (20 genera, 21 species) and Nyafta (15 genera, 19 species) formations. In total, we identified 27 species of 23 genera among hundreds microfossils of variable morphology, which had been macerated form all studied samples. Several of morphotypes, occurring in variable combinations in all three assemblages, represent taxa that have not been described before. Small- and medium-sized acritarchs lacking distinct ornamentation prevail in all three assemblages. Large, morphologically diverse vesicles, filamentous and complex morphotypes are less abundant than simple acritarchs, and all assemblages are nearly lacking colonial coccoidal forms.

Biostratigraphic analysis implies that transit Late Proterozoic taxa dominate in taxonomic composition of studied microfossils. These are acritarchs *Leiominuscula minuta, Leiosphaeridia atava, L. minutissima, L. tenuissima L. jacutica, L. bicrura, L. ternata, Nucellosphaeridium nordium, Pterospermopsimorpha insolita, P. pileiformis, Satka* sp., *Germinosphaera* sp., *Leiotrichoides typicus, Archaeotrichion contortum*, and some other forms, which are confined to one, several, or to all microphytological levels. The listed transit taxa just imply that their host deposits belong to the upper Precambrian (*Stratotype of the Riphean...*, 1982; *Precambrian Microfossils...*, 1989; Knoll, 1994; Veis *et al.*, 2003; Sergeev, 2003). Data on more remarkable morphotypes present in the Vashka, Peza, and Safonovo microbiotas bring forth the desirable details.

Dominant in the least diverse Vashka assemblage (microphytological levels 1 to 9, depth range 4203–3647 m) are morphologically simple acritarchs *Leiosphaeridia, Nucellosphaeridium, Pterospermopsimorpha*, and filamentous sheaths *Archaeotrichion.* Acritarchs are less than 280 μm in diameter (a few specimens of larger *L. ternata* represent an exception), and sheaths are as long as the smallest filamentous forms of the Precambrian (1 to 2 μm). These dominant forms occur in association with formerly unknown morphotypes represented by ribbon-like structureless thalluses and possible reproductive structures of ancient algae and fungi, which are also relatively small and lacking any intricate ornamentation. In the Riphean stratotype (southern Urals) and hypostratotype (Uchur–Maya region), all forms mentioned above occur in the Lower, Middle, and Upper Riphean strata without a selective confinement to any particular interval.

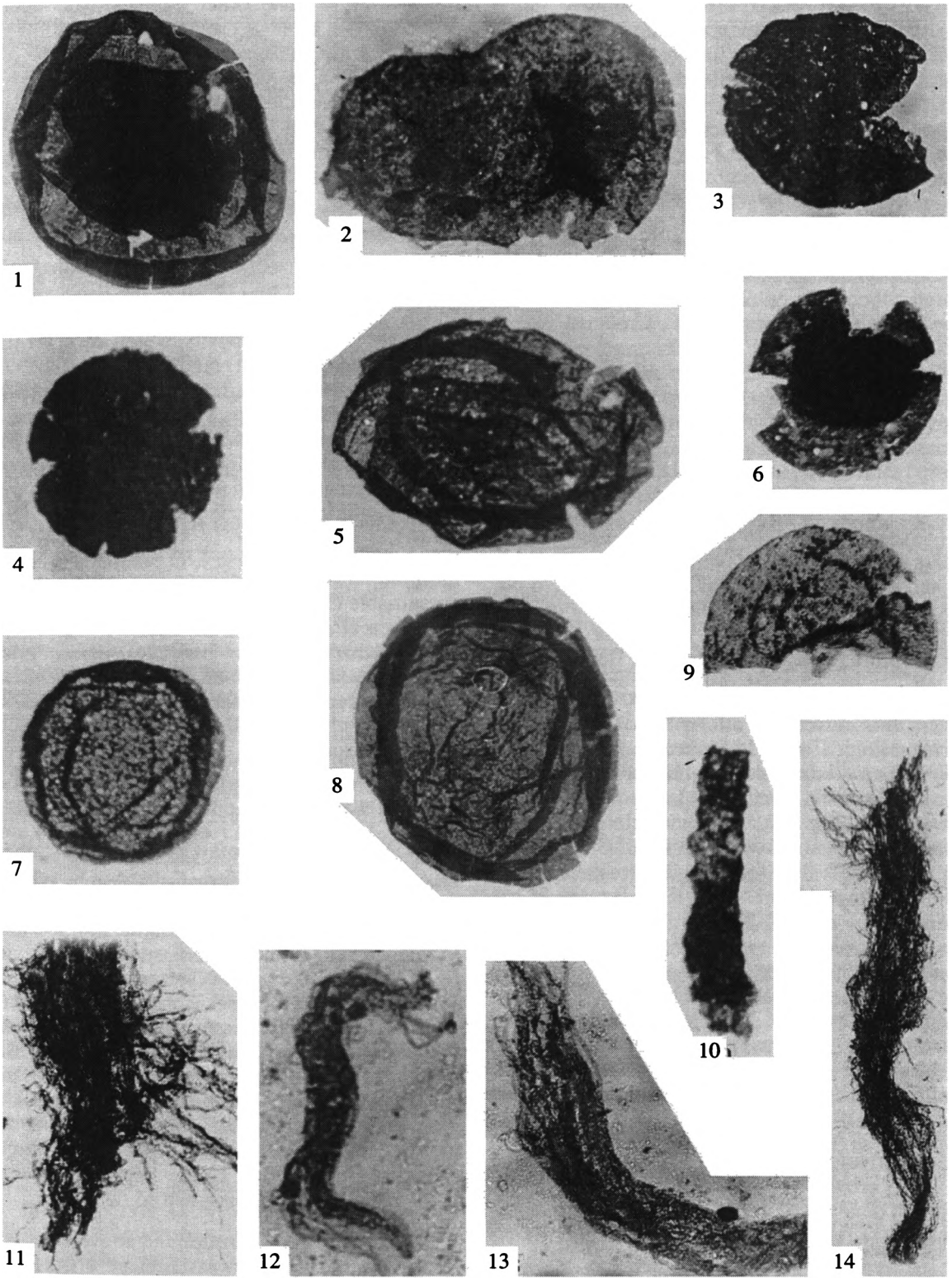
Near the Vashka Formation top (microphytological level 9, depth range 3671–3660 m), the transit Riphean taxa coexists however with spongy *Spumosina* and large ellipsoidal *Navifusa*, which appear firs in the section. In the southern Urals and Siberia, two last morphotypes appear beginning from the levels of the Nugush and/or Kerpyl deposits being untypical of the underlying Lower–Middle Riphean strata (*Stratotype of the Riphean...*, 1982; *Precambrian Microfossils...*, 1989; Veis *et al.*, 1998a, 2003; Sergeev, 2003). In the section of Mezen syneclise, the Vashka assemblage of transit taxa associated with *Spumosina* and *Navifusa* forms is replaced, after a relatively short interval (data of Kuzmenko), by the more representative Peza assemblage that is, as we will see below, very similar to the Early Karatavian Nugush and Kerpyl microbiotas (R_3^1). The aforementioned appearance level of *Spumosina* and *Navifusa* forms suggest, together with a series of important Early Karatavian morphotypes present above, that the Vashka Formation corresponds to relatively high horizons of the Middle Riphean (Yurmatinian).

Plate IV. Late Riphean microfossils from the Mezen syneclise, Russian plate (all the specimens are stored at the Geological Institute, Russian Academy of Sciences, Moscow).

(1) *Pterospermopsimorpha pileiformis* Tim. emend. Mikh., specimen no. 3267–891; (2) "dividing vesicles" (monstrous forms) *Leiosphaeridia* sp. 1, specimen no. 3092–841; (3) *Leiosphaeridia bicrura* Jank., specimen no. 3092–851; (4, 6) *Leiosphaeridia ternata* Jank.: (4) specimen no. 3092–852, (6) specimen no. 3864–209; (5, 7, 9) *Leiosphaeridia jacutica* (Tim.) emend. Mikh. et Jank.: (5) specimen no. 3540–900, (7) specimen no. 3092–853, (9) specimen no. 3864–210; (8) *Chuaria circularis* Walcott emend. Vidal et Ford, specimen no. 3092–840; (10) strongly corroded ribbon-like thallus, specimen no. 3920-217; (11, 14) *Archaeotrichion contortum* Schopf, mats of fine filamentous sheaths: (11) specimen no. 3920–218, (14) specimen no. 3920–219; (12, 13) *Polytrichoides lineatus* Herm. emend. Herm.: (12) specimen no. 3092–854, (13) specimen no. 3092–855.

Stratigraphic confinement: (6, 9–11, 14) Vashka Formation, Middle Riphean; (1–5, 7, 8, 12, 13) Peza Formation, Ust-Nyafta Group, Upper Riphean. Depth interval in borehole Srednyaya Nyafta 21: (10, 11, 14) 3928–3920 m, (6, 9) 3870–3864 m, (5) 3540–3520 m, (1) 3277–3267 m, (2–4, 7, 8, 12, 13) 3105–3092 m. Magnification: (1, 2) ×300, (3, 13) ×150, (4–7, 10) ×100, (8, 9) ×200, (11, 12, 14) ×50.

Plate IV



The main distinctive feature of the Peza assemblage (microphytological levels 10 to 13, depth range 3643–3092 m) consists in the presence of three remarkable and abundant morphotypes unknown from underlying deposits. These are large acritarchs *Chuaria* (up to 480 μm), multiserial sheaths *Polytrichoides*, and wide filamentous *Asperatofilum*. They occur in association with taxa typical of the Vashka Formation, such as simple medium-sized acritarchs *Leiosphaeridia, Pterospermopsimorpha, Nucellosphaeridium* (up to 280–300 μm), and *Navifusa* forms (200 × 400 μm), the latter more frequent than below. From the biostratigraphic standpoint, it is possible to suggest two variants of interregional correlation of the Peza assemblage. (1) The Peza Formation is most likely correlative with a lower part of the type and reference sections of the Upper Riphean. This part also yields three aforementioned morphotypes of the Peza assemblage, although acanthomorphic forms (besides small problematic *Trachyhystrichosphaera parva* Mikh.) have not been encountered there (pre-Bederysh part of the Zilmerdak Formation of southern Urals, Kerpyl Group and Bezymyannyi Formation in central Siberia; microbiota R_3^1). (2) It is less likely that the Peza Formation is correlative with higher Upper Riphean horizons, which yield not only the taxa under consideration, but also acritarchs with diverse processes and other morphotypes of a complex structure (Derevnya Formation, Bederysh and Lakhanda groups; microbiota R_3^2). Both inferences are inconsistent with correlation inferable from the alternative geochronological model of Precambrian biota evolution, which is incompatible with biostratigraphic considerations (Veis *et al.*, 2000, 2001). According to generalized geochronological data, the correlative Nugush, Kerpyl, and Bezymyannyi microbiotas of Siberia (and the Peza assemblage therefore) should be attributed to the Middle Riphean (microbiotas R_{1-2}; Bartley *et al.*, 2001; Semikhatov *et al.*, 2002; Sergeev, 2003; Petrov, 2004). In this connection, it is necessary to note that the Yurmatinian age of Peza assemblage is independently inferable from other correlation schemes, which supported by some authors of present paper and are based on the analysis of Riphean sedimentary cycles in the Mezen syneclise, other East European areas, and, partly, in the southern Urals.

The abundant and most diverse Safonovo microbiota (microphytological levels 14 to 17, depth range 2523.7–2080) crowns the succession of microfossils from Riphean deposits of the Mezen syneclise. In addition to many taxa rising up to this level from underlying deposits (*Chuaria, Spumosina, Navifusa, Polytrichoides*, and *Asperatofilum* included), this microbiota includes abundant morphotypes of a complex morphology, which, being significant in terms of biostratigraphy, do not occur below the Leshukon and Nyafta formations. These are acanthomorphic acritarchs *Trachyhystrichosphaera aimika, T. stricta, T. vidalii, Prolatoforma aculeate*, and forms close to *Cymatiosphaeroides*. The other characteristic taxa of the Safonovo assemblage are peculiar acritarchs *Chuaria globosa* with thickened rims, ellipsoidal *Konderia elliptica, Pseudotawuia* with broadened endings, filmy *Pellicularia*, vesicles *Caudosphaera expansa* with long processes, several varieties of ramified thalluses *Ulophyton*, asymmetric *Globiferum*, frequently segmented cuticular remains, very broad filamentous *Plicatidium, Fabiformis* of distorted ellipsoidal shape, and some others.

In all Riphean sections with well-studied microphytological remains, first of all in the Riphean stratotype and hypostratotype, all complex morphotypes listed above are typical of deposits, which are certainly of the Late Riphean age (Nagovitsin, 2001; Veis and Vorob'eva, 2002; Veis *et al.*, 2003; Sergeev, 2003). Only some of them (e.g., *Chuaria, Spumosina, Polytrichoides*, and *Asperatofilum*) rise up into Vendian strata in some areas (Burzin, 1994, 1998, 1999). In changeable combinations, all these morphotypes represent dominants in microbiotas R_3^1–R_3^4 from different localities. Owing to prevalence of well-preserved acanthomorphic *Trachyhystrichosphaera* and *Prolatoforma*, presumable *Cymatiosphaeroides*, and some other peculiar forms (*Pellicularia, Globiferum*, segmented cuticular remains) in the assemblages, it is impossible to correlate the Leshukon and Nyafta formations with pre-Bederysh deposits of the Karatau Group in southern Urals or with their Siberian analogues, which correspond to basal interval of the Upper Riphean type sections (microbiotas R_3^1). Similarly, the Safonovo assemblage of microfossils cannot be correlated with very representative microbiota (R_3^4) of the Svanbergfjellet Formation of northeastern Spitsbergen, which terminates the composite succession of key Upper Riphean microbiotas of northern Eurasia. In addition to *Trachyhystrichosphaera* and *Cymatiosphaeroides* characteristic of the Leshukon and Nyafta formation, microbiota from Spitsbergen includes *Comasphaeridium, Gorgoniosphaeidium, Palaeoastrum, Valkyria*, and some other forms, which have not been found in the Safonovo group and appear to be more advanced and "younger" morphotypes (Butterfield, 1994). Thus, we failed at present to find biostratigraphic analogues of the Svanbergfjellet microbiota in the Riphean section of Mezen syneclise (in the other Upper Riphean successions of Russia, they are also unknown so far).

Taking into consideration the above constraints, we think that the Safonovo assemblage of microfossils is most likely correlative with Middle Karatavian microbiotas (R_3^{2-3}) from the South Uralian and Siberian sections. This relatively broad stratigraphic interval seems to be acceptable in distinction from the less convincing variant of the assemblage correlation with the Bederysh

(Muldakaevo) microbiota of a narrower range (R_3^2) from southern Urals. As is known from all localities of Bederysh microbiota in the stratotype area, percentage of acanthomorphic forms in it is negligible (Veis *et al.*, 1990, 2002; Mikhailova and Podkovyrov, 1992). A higher abundance of these and some other complicated forms is established however in presumably concurrent deposits (R_3^2) of the Cis-Urals and Siberia, namely in the Priyutovo (Karmala), Shikhan (Savaleevo), lower Lakhanda, and Derevnya formations (Yankauskas, 1982; Veis, 1988; German, 1990: Petrov and Veis, 1995). Thus, the lowest stratigraphic level that can be suggested for the Safonovo microbiota with abundant acanthomorphic acritarchs is the interval of Bederysh (Lakhanda, Derevnya) strata of the Upper Riphean.

The other variant of correlation can be substantiated by new, more comprehensive microphytological characterization of the South Uralian stratotype and Siberian reference section of the Riphean. According to this variant more preferable in our opinion, the Safonovo microfossil assemblage with abundant acanthomorphic *Trachyhystrichosphaera, Prolatoforma, Cymatiosphaeroides* and other taxa in common (*Pellicularia, Fabiformis, Globiferum*) is correlative with the lower Inzer (Shishenyak) microbiota (R_3^3) of the Riphean type section and with similar Miroedikha microbiota of the Turukhansk uplift in Siberia (Veis *et al.*, 1998a, 1998b, 2003; Veis and Vorob'eva, 2002).

The above conclusion is consistent with microphytological data obtained not long ago from borehole No. 1000 located within the area under consideration (Sivertseva, 1993). This borehole was drilled in the axial zone of the Zimnegorsk (Tuchka) aulacogen distinguished in the northwest of the Mezen syneclise (Yakobson *et al.*,). The succession of Upper Precambrian rocks was penetrated here in the depth interval of 1122–173 m. Based on consistent geological and paleontological data, this interval was divided into the Upper Vendian (923–173 m) and Riphean (1122–970 m) parts separated by strata (970–908.5 m) barren of Vendian or Riphean microfossils. The interval of Riphean deposits is composed of gray to variegated, finely interbedded shales, siltstones, and sandstones with a high content of calcareous material. These deposits 260 to 290 m thick in total are attributed to the Tuchka Formation (Yakobson *et al.*, 1991).

Sivertseva (1993) who studied plentiful samples from the depth interval 1100–979 m recovered abundant well-preserved microfossils, mostly acritarchs and filamentous morphotypes. According to her data, the Tuchka microbiota consists of microfossils representing 31 species of 16 genera, many of which are close to taxa occurring at various Karatavian levels in southern Urals and in the Upper Riphean Kama, Lakhanda, and Miroedikha microbiotas of Siberia. These are *Chuaria, Kirbia, Miroedichia, Cucumiforma, Leiofusidium, Polytrichoides* (new species *P. oligofilum* included), *Plicatidium*, and *Glomovertella*. The comparative analysis showed that the Tuchka and Safonovo microbiotas are distinctly correlative (morphotypes in common are giant *Chuaria*, acanthomorphic acritarchs, multiserial sheaths, and some others). These data once more suggest that both the Safonovo and Tuchka assemblages are counterparts of the Middle Karatavian microbiotas.

Golubkova (2002) who was first to study microfossils from Riphean deposits penetrated by borehole Srednyaya Nyafta 21 accepted in her work opinion of A.M. Zharkov (VNIGRI, St. Petersburg) that the depth interval 4203–3126 m in the above borehole corresponds to the "Peza" formation in a broad sense. In samples spanning the depth range of 3859–3625 m, she identified, in addition to transit taxa, the following characteristic morphotypes: *Chuaria circularis, Glomovertella glomerata, Tasmanites* aff. *T. ripheicus*, and (?) *Cymatiosphaeroides* sp. Based on preliminary identifications of four last taxa, Golubkova suggested that all pre-Vendian strata above the depth level of 3859 in the borehole Srednyaya Nyafta 21 should be attributed to the undivided Upper Riphean. We jointly revised all the Golubkova's material and can state now that complex spongy and/or acanthomorphic acritarchs typical of relatively high Upper Riphean horizons do not occur below the Safonovo Group, and that large *Chuaria* of the Karatavian aspect are absent in strata underlying the Peza Formation (below depth level 3647 m). Thus at present, there is no biostratigraphic evidence that strata below this level are of the Late Riphean age. At the same time, data obtained by Golubkova (2002) imply that small subspiral aggregates of narrow filamentous sheaths, which should be classed with *Obruchevella* rather than with *Glomovertella*, are components of the Vashka microbiota (depth interval 3859, 3783, and 3662 m).

ACKNOWLEDGMENTS

We are grateful to M.A. Semikhatov for valuable comments and recommendations in the course of our work. We thank also V.G. Olovyanishnikov who stimulated this study of Riphean microfossils from the Mezen syneclise and M.B. Burzin who donated samples for our research and constructively commented manuscript. Kind assistance of T.V. Vladimirova, V.Ya. Rassomakhin, N.N. Kosenkova, S.S. Shutov, and B.A. Yaralov is appreciated. P.A. Fokin and V.I. Murav'ev helped us in petrographic description of studied rock samples. The work was supported by the Russian Foundation for Basic Research, project nos. 02-05-64333 and 01-05-64719.

Reviewers M.B. Burzin and V.G. Olovyanishnikov

REFERENCES

1. M. B. Burzin, "Main Trends in Historical Development of Phytoplankton during the Late Precambrian and Early Cambrian," in *Ecosystem Reorganizations and Evolution of Biosphere* (Nauka, Moscow, 1994), pp. 51–62 [in Russian].
2. M. B. Burzin, "The Late Vendian Paleobiogeography of Russian Platform," in *Vendian to Early Paleozoic Paleogeography of Northern Eurasia* (Inst. Geol. Geokhim. Ural. Otd. Ross. Akad. Nauk, Yekaterinburg, 1998), pp. 136–146 [in Russian].
3. M. B. Burzin, "Vendian Organic-Walled Microfossils: Biostratigraphic Potential and Significance for Genetic Interpretation of Oil-Source Beds," in *Proc. All-Russia Conference: Stratigraphy, Paleontology, and Potential of Petroliferous Formations in East European Platform* (Inst. Geol., Ufa, 1999), pp. 15–17 [in Russian].
4. M. B. Burzin and Yu. T. Kuzmenko, "Specification of Vendian Stratigraphic Scheme for the Mezen Syneclise," in *Actual Problems of Mining Geology in Sedimentary basins of North European Russia* (Geoprint, Syktyvkar, 2000), pp. 39–40 [in Russian].
5. N. J. Butterfield, A. H. Knoll, and K. Swett, "Paleobiology of the Neoproterozoic Svanbergfjellet Formation, Spitsbergen, Fossil and Strata, No. 15, 1–84 (1994).
6. N. J. Butterfield and R. H. Rainbird, "Diverse Organic-Walled Fossils, Including "Possible Dinoflagellates" from Early Neoproterozoic of Arctic Canada," Geology **26** (11), 963–966 (1998).
7. *Earth's Earliest Biosphere*, Ed. by J. W. Schopf (Princeton Univ. Press, New Jersey, 1983).
8. T. N. German, *Organic World a Billion Years Ago* (Nauka, Leningrad, 1990).
9. E. Yu. Golubkova, "Distribution of Microfossils in Upper Proterozoic Deposits, Borehole Section Srednyaya Nyafta 21," in *Proc. X Palynological Conference: Methodic Aspects of Palynology* (Inst. Geol. Razved. Goryuch. Iskop., Moscow, 2002) pp. 62–64 [in Russian].
10. J. M. Hayes, I. R. Kaplan, and K. W. Wedeking, "Precambrian Organic Geochemistry, Preservation of the Record," in *Earth's Earliest Biosphere*, Ed. by J. W. Schopf (Princeton Univ. Press, New Jersey, 1983), pp. 93–132.
11. E. J. Javaux, A. H. Knoll, and M. R. Walter, "Morphology and Ecological Complexity in Early Eukaryotic Ecosystems," Nature **412** (6872), 66–69 (2001).
12. H. Knoll, "Proterozoic and Early Cambrian Protists: Evidence for Accelerating Evolutionary Tempo," Proc. Nat. Acad. Sci. USA **91** (6), 6743–6750 (1994).
13. H. Knoll and V. N. Sergeev, "Taphonomic and Evolutionary Changes Across the Mesoproterozoic-Neoproterozoic Transition," Neues Jahrb. Paläontol., Abh. **1–3**, 289–302 (1995).
14. N. G. Konopleva and E. K. Fanderflit, "The Pachelma Assemblage of Microfossils from Upper Precambrian Deposits, Northern Areas of East European Platform," in *Paleontology of Precambrian and Early Cambrian* (Nauka, Leningrad, 1979), pp. 159–163 [in Russian].
15. N. S. Mikhailova, and V. N. Podkovyrov, "New Data on Organic-Walled Microfossils from Upper Precambrian Deposits of the Urals," Izv. Akad Nauk SSSR, Ser. Geol., No. 10, 111–123 (1992).
16. K. E. Nagovitsin, Candidate's Dissertation in Geology and Mineralogy (Novosibirsk, 2001).
17. V. G. Olovyanishnikov, "Upper Precambrian of Timan and Eastern Mezen Syneclise," in *Vendian–Early Paleozoic Paleogeography of Northern Eurasia* (Ural. Otd. Ross. Akad. Nauk, Yekaterinburg, 1998), pp. 147–159 [in Russian].
18. P. Yu. Petrov and A. F. Veis, "Facies–Ecological Structure of the Derevnya Formation Microbiota: Upper Riphean, Turukhansk Uplift, Siberia," Stratigr. Geol. Korrelyatsiya **3** (5), 13–40 (1995) [Stratigr. Geol. Correlation **3**, 435–452 (1995)].
19. *Precambrian Microfossils of the USSR* (Nauka, Leningrad, 1989).
20. *Riphean and Vendian of the North European USSR*, Ed. by V. G. Getsen *et al.* (Oblknigoizdat, Vologda, 1987).
21. V. A. Rudavskaya, L. S. Kossovoi, and S. P. Tyunegin, "Stratigraphic Subdivision of Upper Precambrian in the Mezen Syneclise, the North of Russian Platform," in *Precambrian Stratigraphy* (Nauka, Leningrad, 1977), pp. 7–15 [in Russian].
22. M. A. Semikhatov, "Methodical Principles of the Riphean Stratigraphy," Stratigr. Geol. Korrelyatsiya **3** (6), 50–67 (1995) [Stratigr. Geol. Correlation **3**, 559–576 (1995)].
23. M. A. Semikhatov, A. B. Kuznetsov, J. M. Gorokhov, *et al.*, "Low $^{87}Sr/^{86}Sr$ Ratios in Seawater of the Grenville and post-Grenville Time: Determining Factors Stratigr. Geol. Korrelyatsiya **10** (1), 3–46 (2002) [Stratigr. Geol. Correlation **10**, 1–41 (2002)].
24. V. N. Sergeev, "Silicified Microfossils from the Avzyan Formation of Southern Urals," Paleontol. Zh., No. 2, 103–111 (1992).
25. V. N. Sergeev, Doctoral Dissertation in Geology and Mineralogy (Moscow, 2003).
26. A. Sivertseva, "The Tuchka Microbiota from Upper Riphean, White Sea Region," Dokl. Ross. Akad. Nauk **332** (5), 621–623 (1993).
27. *Stratotype of the Riphean: Paleontology and Paleomagnetism* (Nauka, Moscow, 1982).
28. *Tectonics of Petroliferous Regions in the RSFSR, Explanatory Notes to the Tectonic Map, Scale 1 : 2500000* (Tsentrgeologiya, Moscow, 1988).
29. *The Proterozoic Biosphaere*, Ed. by J. W. Schopf (Cornelius Klein, London, 1992).
30. *The Upper Precambrian in the North European USSR (Explanatory Notes to Stratigraphic Scheme)* (Komi Fil. Akad. Nauk SSSR, Syktyvkar, 1986).
31. F. Veis, "Riphean and Vendian Microfossils from the Uchur–Maya and Turukhansk Regions of Siberia," Izv. Akad. Nauk SSSR, Ser. Geol., No. 5, 47–64 (1988).
32. F. Veis and P. Yu. Petrov, "The Main Peculiarities of the Environmental Distribution of Microfossils in the Riphean Basins of Siberia," Stratigr. Geol. Korrelyatsiya **2** (5), 97–129 (1994) [Stratigr. Geol. Correlation **2**, 397–428 (1994)].
33. F. Veis and N. G. Vorob'eva, "Microbiotas of the Kerpyl' Group in the Riphean Hypostratotype of Siberia," Stratigr. Geol. Korrelyatsiya **1** (1), 41–58 (1993) [Stratigr. Geol. Correlation **1**, 1–35 (1993)].

34. F. Veis, E. V. Kozlova, and N. G. Vorob'eva, "Organic-Walled Microfossils from the Riphean Type Section (Southern Urals)," Izv. Akad. Nauk SSSR, Ser. Geol. No. 9, 20–36 (1990).

35. F. Veis, P. Yu. Petrov, and N. G. Vorob'eva, "Secular Transformations in the Facies–Ecological Structure of Ancient Biotas and the Riphean Stratigraphy," Geol. Geofiz. **39** (1), 85–96 (1998).

36. F. Veis, P. Yu. Petrov, and N. G. Vorob'eva, "The Late Riphean Miroedikha Microbiota from Siberia. Part: Interpretation in Terms of Biotic Paleosuccession, Stratigr. Geol. Korrelyatsiya **7** (1), 18–40 (1999) [Stratigr. Geol. Correlation **7**, 15–34 (1999)].

37. F. Veis, P. Yu. Petrov, and N. G. Vorob'eva, "Geochronological and Biostratigraphic Approaches to Reconstruction of Precambrian Biota Evolution: New Finds of Microfossils in Riphean Sections on the Western Slope of the Anabar Uplift," Dokl. Ross. Akad. Nauk **378** (4), 511–517 (2001) [Doklady Earth Science **378**, 413–419 (2001)].

38. F. Veis, N. N. Larionov, N. G. Vorob'eva, and Lee Seong-Joo, "Significance of Microfossils for Riphean Stratigraphy of the Southern Urals (Bashkirian Meganticlinorium) and Adjacent Regions (Kama-Belaya Aulacogen)," Stratigr. Geol. Korrelyatsiya **8** (5), 3–28 (2000) [Stratigr. Geol. Correlation **8**, 423–446 (2000)].

39. K. E. Yakobson and M. Yu. Kuznetsova, "A Problem in Correlation of Pre-Vendian Unmetamorphosed Successions of the Russian Platform," Sov. Geol., No. 11, 44–48 (1991).

40. T. V. Yankauskas, Candidate's Dissertation in Geology and Mineralogy (Moscow, 1982).

41. S. Xiao, A. H. Knoll, and A. J. Kaufman, "Neoproterozoic Fossils in Mesoproterozoic Rocks? Chemostratigraphic Resolution of a Biostratigraphic Conundrum From the North China Platform," Precambrian. Res. **84**, 197–220 (1997).

Stratigraphy and Geological Correlation, Vol. 12, No. 6, 2004, pp. 572–587. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 12, No. 6, 2004, pp. 36–52.
Original Russian Text Copyright © 2004 by A. A. Sorokin, Ponomarchuk, A. P. Sorokin, Kozyrev.
English Translation Copyright © 2004 by MAIK "Nauka/Interperiodica" (Russia).

Geochronology and Correlation of Mesozoic Magmatic Complexes in the Northern Margin of the Amurian Superterrane

A. A. Sorokin*, V. A. Ponomarchuk, A. P. Sorokin*, and S. K. Kozyrev*****

**Department of Regional Geology and Hydrogeology, Amur Research Center, Far East Division, Russian Academy of Sciences, Blagoveshchensk, Russia*

***Joint Institute of Geology, Geophysics, and Mineralogy, Siberian Division, Russian Academy of Sciences, Novosibirsk, Russia*

****Federal State Unitary Geological Company "Amurgeologiya," Ministry of Natural Resources of Russian Federation, Blagoveshchensk, Russia*

Received April 16, 2003; in final form, November 20, 2003

Abstract—A subject of discussion is age of rocks in Mesozoic volcano-plutonic belts of the epi-Paleozoic Amurian superterrane. Mesozoic volcanic and intrusive complexes of the northeastern Greater Khingan and western Umlekan–Ogodzha volcano-plutonic belts are dated using the $^{40}Ar/^{39}Ar$ method of isotopic geochronology. The results obtained and dates published before are used to elaborate the correlation scheme for magmatic rocks of both belts. Similarity and distinctions in Mesozoic evolution of two structural zones under consideration are elucidated for the Late Jurassic, Early Cretaceous, and Early–Late Cretaceous boundary periods.

Key words: $^{40}Ar/^{39}Ar$ dating, isotopic geochronology, Mesozoic, correlation, volcano-plutonic belt, Amurian superterrane, Greater Khingan.

INTRODUCTION

Distribution areas of Mesozoic volcanic and plutonic rocks are widespread along the eastern margin of Asiatic continent (*Volcanic Belts...*, 1984; Zonenshain *et al.*, 1990; Gusev and Khain, 1995; *Geological Map...*, 1999; Gordienko *et al.*, 2000; Yarmolyuk *et al.*, 1995, 2000; Kovalenko *et al.*, 1999; Zhan Hung *et al.*, 2000). The areas isolated or grouped into volcano-plutonic belts were formed in different geodynamic settings influenced by subduction zones, collision events, and intraplate magmatic activity. A correct interpretation of geodynamic environments that controlled magmatic activity and, eventually, geological development of eastern Asia during the Mesozoic is impossible without a reliable correlation of magmatic events in different areas of the entire region. Unfortunately, such a correlation cannot be substantiated in many cases, because the necessary geochronological information is unavailable.

The northern and eastern margins of the epi-Paleozoic Amurian superterrane (Fig. 1) represent geological zones, where Mesozoic magmatism developed most intensely. The superterrane or microcontinent is a heterogeneous structure composed of lesser terranes (Kerulen–Argun, Mamyn, Bureya–Jiamusi–Khanka and other blocks), which amalgamated into an integral continental mass by the end of the Paleozoic (Zonenshain *et al.*, 1990; Parfenov *et al.*, 1999). In the north, the superterrane is bounded by the Mongol–Okhotsk fold belt, while its southern boundary is defined by paleoceanic structures of the Solonker zone in southern Mongolia, which ceased to develop in the earliest Triassic. Mesozoic structures of the Sikhote Alin orogenic belt represent the eastern limitation of the superterrane, whereas its western termination is blurred in Caledonian and Hercynian structures of eastern Mongolia (Zonenshain *et al.*, 1990; Parfenov *et al.*, 1999).

A universal zoning of Mesozoic magmatism in the northern margin of the Amurian superterrane has not been elaborated yet. In general, researchers used to consider the Mongol–Transbaikal, Greater Khingan, and Umlekan–Ogodzha volcano-plutonic belts as separate structural zones or megazones (Fig. 1). In the eastern Transbaikal region, the Mongol–Transbaikal belt is spread over the Kerulen, Argun, Gazimur, and Shilka river basins. Extending northeastward for a distance more than 1500 km, this belt is superimposed onto the southern flank of western segment of the Mongol–Okhotsk belt and partially on structures of that belt proper (*Geological Map...*, 1999; Gordienko *et al.*, 2000; Yarmolyuk *et al.*, 1995, 2000). The Dzhalair-Nuur (*Geological Map...*, 1999) or Daerbulan (Gordienko *et al.*, 2000) fault system separates the Mongol–Transbaikal volcano-plutonic belt from the Greater Khingan belt embracing a considerable area of northeastern China (Fig. 1). The Greater Khingan belt striking north-northeastward for a distance over 1000 km corresponds to the main part of synonymous mountain system. Further eastward, there is the Umlekan-Ogodzha volcano-plutonic belt (Parfenov, 1984; Mar-

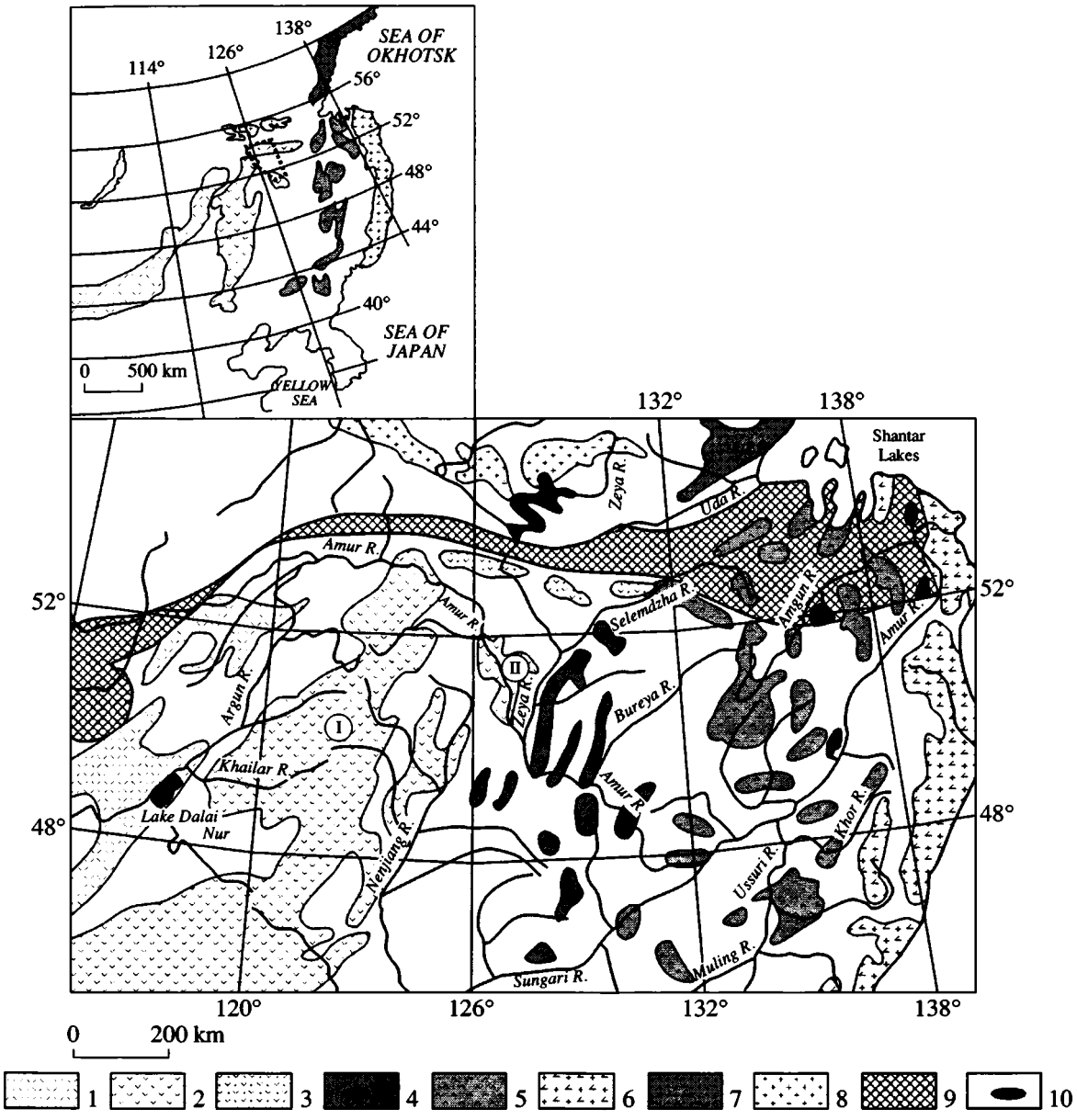


Fig. 1. Distribution areas of Mesozoic volcanic rocks and volcano-plutonic belts of the Asia eastern margin (after *Geological Map...*, 1999, with modifications; study region is shown by dashed contour in the inset map): (1) Mongol–Transbaikal belt; (2) Greater Khingan belt; (3) Umlekan–Ogodzha belt; (4) Lower Zeya volcanic area; (5) Khingan–Okhotsk belt; (6) East Sikhote Alin belt; (7) Uda belt; (8) Stanovoi belt; (9) Mongol–Okhotsk foldbelt; (10) large lakes; encircled numbers denote volcanic fields of the Greater (I) and Lesser (II) Khingan ridges.

tynyuk *et al.*, 1990; *Geological Map...*, 1999) extending along the northern margin of the Amurian superterrane, where it is traceable for a distance greater than 500 km, being adjacent to the Mongol–Okhotsk foldbelt (Fig. 1). There is a viewpoint that the Umlekan–Ogodzha volcano-plutonic belt is a continuation of the Greater Khingan belt, both representing constituents of the integral East Asian volcano-plutonic megazone (*Geological Map...*, 1999).

The Mesozoic magmatism in the northern margin of the Amurian superterrane is of a debatable origin. Zonenshain *et al.* (1990) were among those who first suggested two possible geodynamic settings for the magmatic activity, i.e., the influence of subduction zone or the "hot spot" impact. Both versions dominated in publications until recently (Kovalenko *et al.*, 1999; Yarmolyuk *et al.*, 1999, 2000; Gordienko *et al.*, 2000; Moiseenko *et al.*, 2000). Khanchuk (2000) suggested alternatively that Mesozoic magmatism under consideration could have been connected with the transform margin settings.

The problem solution needs in a reliable correlation of geological events. The former correlation based on formational similarities of magmatic complexes in different areas of the vast region does not seem to be reliable without proper substantiation by desirable geochronological dates. In this work, we consider new geological, paleontological, geochemical, and isotopic-geochronological data elucidating age relations and compositional peculiarities of magmatic rocks in the western Umlekan–Ogodzha and northern Greater Khingan belts. A preliminary interpretation was published earlier (Sorokin *et al.*, 2002a, 2002b). In the current comparative analysis, we also used data on geochemistry and successive development of magmatic events in northern and central parts of the Greater Khingan Ridge (Zhao Guolong *et al.*, 1989; Gordienko *et al.*, 2000; Zhan Hung *et al.*, 2000; Fu-yuan Wu *et al.*, 2000; Chun-Sheng Wei *et al.*, 2000; Bor-ming Jahn *et al.*, 2001).

DEVELOPMENT OF MESOZOIC MAGMATISM IN THE GREATER KHINGAN AND UMLEKAN–OGODZHA BELTS

The Greater Khingan belt is one of the largest Mesozoic structures in eastern Asia. Sometimes it has been considered as a synonymous megazone of the Upper Amur belt (Gordienko *et al.*, 2000) or as a volcano-plutonic system of the Greater and Lesser Khingan ridges (*Geological Map...*, 1999).

Data on the belt structure are rather contradictory, especially with respect to age and formational affinity of magmatic complexes. The earliest magmatic rocks of the belt belong to basalt–andesite (latite)–rhyolite series of the Tamulangou Formation, and isotopic dates ranging from 154 to 144 Ma have been obtained by K–Ar, Rb–Sr, and U–Pb methods for some rocks of the series (Zhao Guolong *et al.*, 1989; Gordienko *et al.*, 2000; Zhan Hung *et al.*, 2000). Associated with this period of magmatic activity are large bodies of S- and I-type granitoids (Zhao Guolong *et al.*, 1989; Gordienko *et al.*, 2000). Rocks of the earliest magmatic stage in the Greater Khingan belt are overlain by sediments of the Mingshui Formation that yields organic remains *Nestoria pissovi* Krasinetz, *Coniopteris silapensis* Prinada, and *Frenelopsis* sp. of the Late Jurassic–earliest Cretaceous, which define the upper stratigraphic limit of the stage (Gordienko *et al.*, 2000; Zhan Hung *et al.*, 2000). The subsequent Jixiangfeng and Shangkuli volcanic series of trachydacite–rhyolite (Zhan Hung *et al.*, 2000) or differentiated andesite–rhyolite composition (Gordienko *et al.*, 2000) are of a less definite stratigraphic position. According to Zhan Hung *et al.* (2000), K–Ar dates obtained for these rocks range widely from 126 to 104 Ma, and intercalated sediments bear fossils of the terminal Early Cretaceous (of the early Gault). In addition, there are known a series of Rb–Sr and Sm–Nd isochron dates from 122 to 130 Ma, which have been obtained for A-type granitoid intrusions of the belt (Bor-ming Jahn *et al.*, 2001; Chun-Sheng Wei *et al.*, 2000; Fu-yuan Wu *et al.*, 2000). The Early–Late Cretaceous boundary period was marked in the belt by formation of basaltic trachyandesite and trachyandesite lava flows, the isotopic age of which is 105 to 88 Ma (Gordienko *et al.*, 2000; Zhan Hung *et al.*, 2000).

The extreme northeastern flank of the belt hosts volcanic associations of the Lesser Khingan Ridge (*Geological Map...*, 1999), which have been sampled for this study. The ridge extending northwestward represents the northwestern boundary structure of the Amur–Zeya depression (Fig. 2). This structural zone is mainly composed of Precambrian and Phanerozoic granitoids and of associated Mesozoic volcanics, large fields of which are known on the right side of the Amur River. In the riverbank areas that belong to Russia, these fields are frequently concealed under loose Cenozoic deposits.

Mesozoic volcanic rocks of the Amur right bank are traditionally divided into the Itikut and overlying Poyarka formations (Sorokin, 1975; Sidorov, 1981; Martynyuk *et al.*, 1990; *Resolutions...*, 1994). The K–Ar dates known for volcanic rocks of both formations are of a wide range corresponding to the entire Early Cretaceous. Palynological spectra and elements of leaf floras from the volcanic zone under consideration also do not cross boundaries of the Lower Cretaceous, although they are not representative in full measure. Accordingly, ages of the formations were determined based on correlation with deposits of a relatively deeper part of the Amur–Zeya paleobasin, which yield plant remains. As was determined, age of the Itikut Formation corresponds to the Berriasian–Valanginian, while the Poyarka Formation spans the Hauterivian–lower Albian interval (*Resolutions...*, 1994), and the time span of both is close therefore to the Early Cretaceous.

The Greater Khingan belt is lacking a distinct northern boundary (Figs. 1, 2). This situation was likely responsible for assumption that this and the Umlekan–Ogodzha belt of the Amur River upper courses are interconnected, but this has never been controlled by data on composition of volcanic rocks. In the last belt, a wide spectrum of magmatic rocks war formerly divided into a series of plutonic and volcanic complexes. These are the Late Jurassic (?) Magdagachi Complex of subalkaline and alkaline granites and granite porphyries, the Early Cretaceous (or Late Jurassic–Early Cretaceous) Upper Amur Complex of granites and granodiorites, the Early Cretaceous Burinda Complex of gabbro–monzonite–granodiorite composition, and volcanic-to-subvolcanic Taldan, Kerak, and Gal'ka complexes (*Geology of the BAM...*, 1988; Martynyuk *et al.*, 1990). The subdivision scheme was corrected in the course of recent investigations (Kozyrev *et al.*, 2001), when the Kerak Complex was abolished, and formational affinities of some other complexes and their interrelations were reconsidered. Isotopic ages of magmatic rocks remained of a wide range however and need in a verification.

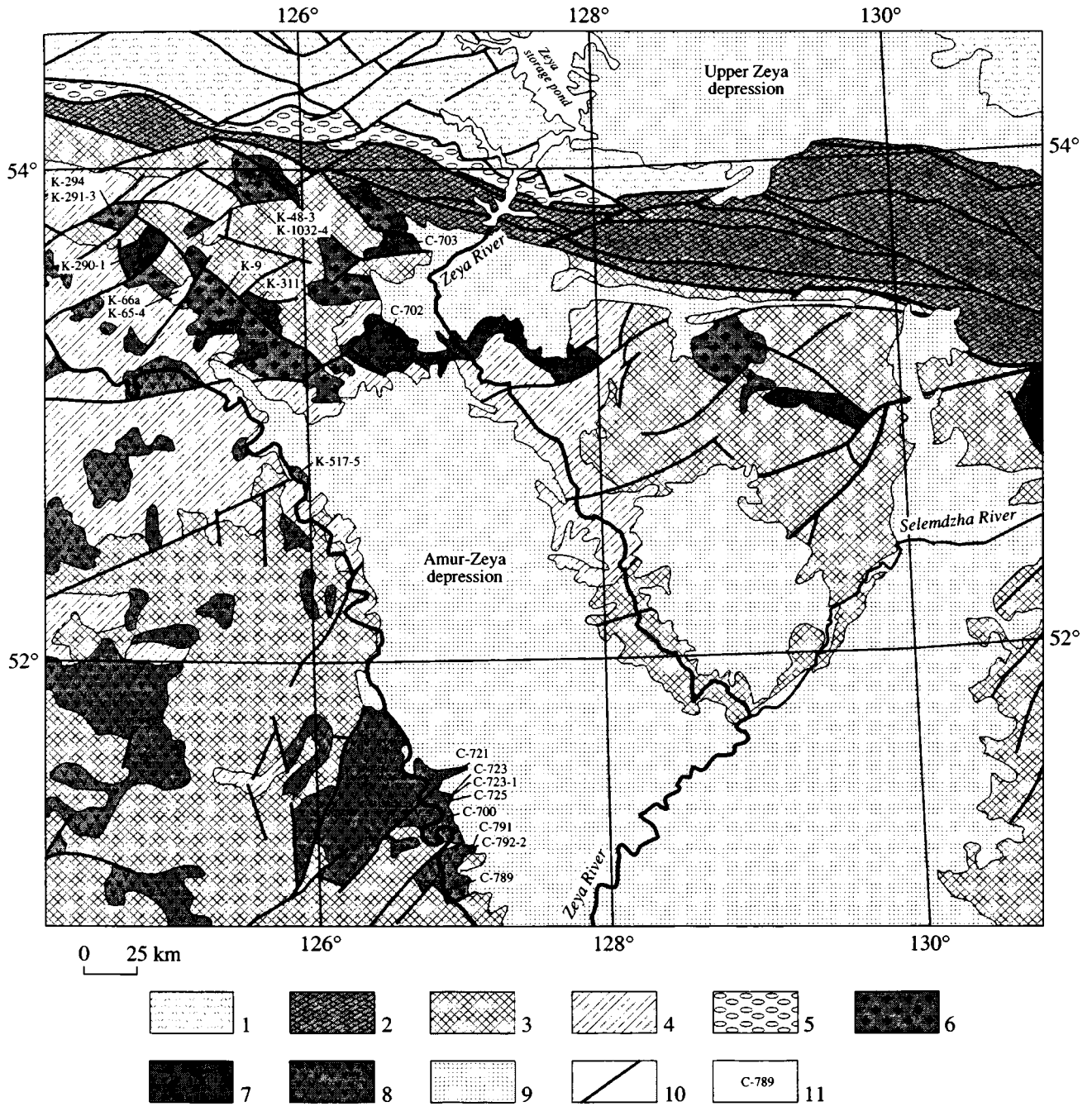


Fig. 2. Geological map of the study region (after *Geological Map...*, 1999, with modifications): (1) southern margin of Siberian craton; (2) Paleozoic oceanic formations of the Mongol–Okhotsk foldbelt; (3) pre-Mesozoic metamorphic and intrusive complexes of the Amurian superterrane; (4) Jurassic flyschoid deposits of the Upper Amur and Zeya–Dep paleobasins; (5) Upper Jurassic–Lower Cretaceous conglomerates; (6) Early Mesozoic intrusive complexes; (7, 8) volcanic complexes of the Umlekan–Ogodzha (7) and Greater Khingan (8) belts; (9) Cenozoic deposits of the Amur–Zeya depression; (10) principal faults; (11) sampling sites and their numbers corresponding to those in the text, table, and figures.

ANALYTICAL METHODS

Bulk composition and geochemistry of rocks. At the Institute of Geochemistry, Siberian Division, Russian Academy of Sciences (Irkutsk), we used the XRF spectroscopy to analyze the bulk chemistry of rock samples and concentrations of Sr, Zr, and Nb, while concentrations of other trace elements (Ga, Ge, Rb, Cs, Sr, Ba, Pb, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Y, Th, U, Zr, Hf, Nb, Ta, Sc) were measured using the ICP-MS method. In the last case, powdered samples were preliminary dissolved in Teflon containers apply-

ing HF + HNO_3 mixture in proportion 6 : 2, and quadripole mass spectrometer PlasmaQuad II+ was used to measure element concentrations in solutions. The measurement results were corrected based on internal standards of ^{87}In and ^{209}Be. MSWD of trace element concentrations measured in standard samples during the experimental run was less than 10% relative to the attested values.

^{40}Ar–^{39}Ar dating was performed at the Joint Institute of Geology, Geophysics, and Mineralogy, Siberian Division, Russian Academy of Sciences (Novosibirsk) using mass spectrometer MI-1201B and analytical procedure described earlier (Ponomarchuk *et al.*, 1998; Shevchenko *et al.*, 2000). Because of possible presence of xenogenous minerals, which may be responsible for isotopic-geochronological heterogeneity, we dated separate mineral fractions (feldspars, biotite, amphibole) and matrix of the rocks. The dates obtained were corrected applying the standard method with due account for atmospheric contamination and interference peaks of ghost neutron-induced reactions.

Mineral fractions, primarily those unaffected by alterations, were separated after comprehensive petrographic investigation of rock samples under microscope. Minerals lacking visible inclusions were picked up by hands under binocular microscope from grain-size fraction of 0.25–0.15 mm.

Interpreting $^{40}Ar/^{39}Ar$ age spectra, we followed recommendation of Fleck *et al.* (1977). Provisions of calculating plateau ages were as follows: (a) three neighboring steps at least must be used in a calculation; (b) difference between neighboring dates must be not greater than the standard deviation value; (c) the total amount of ^{39}Ar incrementally extracted from a sample in three steps must be not less than 50%. We failed however to meet all the necessary conditions, when impact of geological processes resulted in appearance of isotopic-geochronological heterogeneity and, consequently, in discordant $^{40}Ar/^{39}Ar$ age spectra. In such a case, the formal interpretation of age spectra (Fleck *et al.*, 1977) is supplemented in this work by the following three parameters calculated as recommended by Gustafson *et al.* (2001). (1) *The age averaging result from gas fractions released in all steps* up to the melting temperature; it may be approaching the K–Ar age of a sample being regarded however of a reference value only. (2) *The reduced plateau age* of the given sample, when its gas spectra incompletely satisfy the above formal rules of plateau discrimination (e.g., when amount of extracted ^{39}Ar is less than 50%, one of the steps is discordant, or less than three steps are distinguishable, etc.). This age is calculated for a spectrum part most closely resembling a plateau. (3) *The isochron age* of a line approximating experimental data points in $^{39}Ar/^{40}Ar$–$^{36}Ar/^{40}Ar$ diagram; in this case, intersection points of the approximation line with $^{39}Ar/^{40}Ar$ and $^{36}Ar/^{40}Ar$ axes were used to calculate the sample age and isotopic composition of initial argon, respectively.

As it follows from the table, the plateau (reduced variant included) and isochron ages calculated for a given sample are overlapping as a rule. In some cases, the priority was given to the plateau ages with minimal uncertainties.

We should stress as well that age values calculated for different mineral phases from samples, which have been collected from the same magmatic complexes, are concordant. This result suggests purity of analyzed mineral fractions and representative character of collected samples.

GEOCHRONOLOGY AND GEOCHEMISTRY OF MAGMATIC ROCKS FROM NORTHERN AND NORTHEASTERN AREAS OF THE GREATER KHINGAN BELT

As is mentioned above, there is no distinct boundary between the Greater Khingan and Umlekan–Ogodzha belts, and discrimination criteria for magmatic rocks of both structures are unknown. Accordingly, it is quite difficult to attribute magmatic complexes to one of the belts without doubts, especially in the Amur River upper courses, where the northern part of the former belt and western areas of the latter are conjoint. We studied magmatic rocks characterizing northeastern flank of the Lesser Khingan Ridge and northern flank of the Khumarhe-Jishan Ridge that is a northern spur of the Greater Khingan mountain system (Figs. 1, 2). In regional tectonic schemes, both ridges are included into the Greater Khingan belt.

The Late Jurassic Kudikuncha Complex of trachyandesite–trachyrhyolite composition represents the oldest volcanic rocks. Small lava fields, dikes, and sills of these rocks are folded together with freshwater to continental sediments of the Tolbuzino Formation. An isotopic date of 147 ± 8 Ma has been obtained for trachyrhyolite of the complex by the Rb–Sr age method (Kozyrev *et al.*, 2001).

The Late Jurassic Magdagachi Complex includes moderately alkaline granites and granite porphyries associated with leucogranite and granosyenite porphyries, all forming small to large intrusions, some of which are sill-like in shape. The intrusions cut through the Oxfordian–Tithonian sediments of the Tolbuzino Formation and are overlain by the Berriasian–Valanginian conglomerates of the Peremykino Formation. K–Ar dates of 140 ± 8 (amphibole), 148 ± 8 (biotite), and 145 ± 7 Ma (K-feldspar) characterize subalkaline granites of one of the massifs. The average value of 145 ± 5 Ma (Kozyrev *et al.*, 2001) is consistent with results of geological observations.

The Early Cretaceous Complex of trachyrhyolites and less frequent trachyrhyodacites and subalkaline leucogranite porphyries is represented by small subvolcanic bodies. It is distinguished for the first time, because respective rocks were formerly included into

the Early Cretaceous Itikut Complex of andesitic volcanics.

The complex is distinguished based on results of ^{40}Ar–^{39}Ar dating and specific geochemistry of the rocks. For two trachyrhyolite samples (nos. C-791 and C-792-2), we obtained plateau ages of 133 ± 1.7 and 136.5 ± 1.6 Ma (Table, Figs. 3A and 3B). For the latter sample, we calculated the concordant isochron age of 143.5 ± 1.5 Ma (MSWD = 0.9), whereas the same method brought in an older value of 142 ± 1 Ma (MSWD = 1.8) in the case of former sample. Taking into consideration the concordant ages, we assume that rocks of the complex were formed 136–133 Ma ago and correspond to the Valanginian in stratigraphic scale (Fig. 4).

The Early Cretaceous Itikut Complex predominantly includes andesites, basaltic andesites, andesitic dacites, and less abundant rhyodacites or their tuffs and ignimbrites. Numerous volcanic edifices composed of these rocks are exposed in coastal cliffs of the Amur River. The Itikut Formation and synonymous volcanic complex were traditionally attributed to the Berriasian–Valanginian (*Resolutions...*, 1994).

We established concordant plateau ages ranging from 122.2 ± 0.8 to 125.4 ± 3 Ma for rock samples from the Chernyaevo (Sample K-517-5) and Korsakovo (samples C-723-1 and C-725) volcanic fields. The calculated isochron ages (MSWD from 3.1 to 3.8) are compatible with above values (Table, Figs. 3C and 3D), and all the dates correspond to the Barremian in stratigraphic scale (Fig. 4). The Chernyaevo and Korsakovo fields are situated respectively in the northern termination and central part of the Lesser Khingan Ridge, and the results obtained imply that respective magmatism was widespread in the ridge.

The Early Cretaceous Poyarka Complex is represented by trachybasalts, basaltic trachyandesites, rhyolites, and trachyrhyolites. This complex is of the bimodal type, because basic and acid lavas prevail in its composition. As is shown in geological maps, lava fields of the complex occupy spacious areas, but they are similar in composition to trachybasalt–trachyandesite eruptions of the younger complex (see below), and it is difficult to establish precisely the distribution areas of rocks under consideration. According to traditional viewpoint, the Poyarka Formation and synonymous volcanic complex are the Berriasian–Valanginian in age (*Resolutions...*, 1994).

Concordant plateau and isochron (MSWD = 2.8) ages determined for matrix fraction of basaltic trachyandesite (Sample C-721) and rhyolite (Sample C-723) are within a narrow range of 118–122 Ma (Table, Figs. 3E and 3F). The established dates suggest that respective lavas erupted during the late Barremian–early Aptian (Fig. 4) that is consistent with results of geological observations, since subvolcanic rhyolites (Sample C-723) are in eruptive contacts with trachyandesites of the Itikut Complex (Sample C-723-1).

The Early–Late Cretaceous complex of trachybasalts, basaltic trachyandesites, and trachyandesites is distinguished for the first time, and it is difficult to evaluate distribution areas of respective lavas. Rocks of the complex were formerly considered as constituents of the Poyarka Complex. Our isotopic-geochronological study showed that concordant plateau and isochron ages of 104.6 ± 0.6 Ma (Table, Figs. 3G and 3H) characterize trachyandesites (Sample C-789) of the complex, and respective lavas erupted therefore at about the Early–Late Cretaceous boundary time (Fig. 4).

Thus, the results obtained suggest the following time succession of magmatic events in northern to northeastern flanks of the Greater Khingan belt (Fig. 4). Trachyandesite–trachyrhyolite eruptions of the Late Jurassic Kudikuncha Complex took place approximately 147 Ma ago. Intrusions of moderately alkaline granites and granite porphyries (Magdagachi Complex) originated soon afterward (about 145 Ma ago). These events were followed by eruptions of the Early Cretaceous trachyrhyolite lavas 133–136 Ma ago and then by andesite and trachybasalt–rhyolite volcanism that produced rocks of the Early Cretaceous Itikut (122–125 Ma old) and Poyarka (118–122 Ma old) complexes. The next stage corresponds to eruptions of the Early–Late Cretaceous trachybasalt–trachyandesite lavas 102–105 Ma ago. In addition, we included in our scheme (Fig. 4) one more complex of granodiorite to diorite porphyry dikes, the absolute age of which is unknown. These dikes crosscut andesitic lavas of the Early Cretaceous Itikut Complex but nowhere have been found in contacts with somewhat younger trachybasalt–rhyolite lavas of the Poyarka Complex. Geochemical peculiarities of the studied associations of magmatic rocks are very contrasting.

LILE concentrations in moderately alkaline granites and granite porphyries of the Late Jurassic Magdagachi Complex are close to those in the upper continental crust (Fig. 5A). Distinctive features of these rocks are the positive Sr-anomaly, Nb and Ta minimums, and depletion in heavy REE, particularly in Yb, and in Y that is similar to the last element in geochemical properties.

The Early Cretaceous trachyrhyolites are distinctly enriched in HFSE and REE relative to composition of the upper continental crust. Typical of these rocks are apparent negative anomalies of normalized Ba and Sr concentrations (Fig. 5B) that is characteristic of A-type granitoids. In the normalized rock/primitive mantle diagram (Fig. 6B), basaltic andesites and andesites of the Early Cretaceous Itikut Complex show a moderate enrichment in Ba, Rb, Th, K, light REE and parallel depletion in Nb, Ta, P, Ti, heavy REE, and Y. Similar distribution patterns are characteristic of andesitic eruptions in active continental margins (Pearce *et al.*, 1984; *Magmatic Rocks...*, 1987).

As compared to intermediate and more basic volcanics of the Itikut Complex, younger trachybasalts and

Results of $^{40}Ar/^{39}Ar$ dating of Mesozoic magmatic rocks from northern margin of the Amurian superterrane

Complex	Rock	Sample no.	Fraction	All-steps averaging age*, Ma	Calculated plateau		Isochron parameters		
					Age*, Ma	Extracted ^{39}Ar (%)	Calculated age*, Ma	MSWD	$(^{40}Ar/^{36}Ar)_0$
Western part of the Umlekan–Ogodzha belt									
Trachybasalt–trachyandesite	trachyandesite	C-702	amphibole	94.5	97.5 +/–0.6	57	94+/–1.2	3.0	298+/–2
			xenoliths of volcanic glass	128.6	129.5+/–0.8	92	128.7+/–1	1.02	301+/–10
Gal'ka Complex of trachybasalt–rhyolite series	rhyolite	K-66-a	matrix	–	115.3+/–1.5	75	–	–	–
	trachybasalt	K-65-4	matrix	–	118.7+/–0.9	82	–	–	–
Taldan Complex of andesites	dacitic andesite	K-290-1	plagioclase	116.5	122.9+/–1.2	84	125.4+/–4.2	1.9	290+/–10
	basaltic andesite	C-703	matrix	122.7	127.3+/–1.1	59	125.4+/–1.1	0.6	298+/–2
Burinda Complex of monzodiorite–granodiorite association	quartz monzonite	K-291-3	amphibole	144.7	142.4+/–1.6	85	141.6+/–3.3	0.61	295+/–9
	granodiorite	K-294	whole rock	119	127.2+/–0.9	80	129+/–0.4	1.3	284+/–3
	quartz diorite	K-311	biotite	124	130.2+/–1.3	98	131+/–3.6	0.4	274+/–194
Upper Amur Complex of granite–granodiorite association	granodiorite	K1032-4	amphibole	166	139.9+/–1.1	94	138.9+/–1.4	0.7	298+/–7
	granite	K-48-3	plagioclase	103.6	134.9+/–1.3	31	–	–	–
Northern and northeastern parts of the Greater Khingan belt									
Trachybasalt–trachyandesite volcanic series	trachyandesite	C-789	matrix II	105.9	104.6+/–0.6	72	102.2+/–0.5	4.5	304+/–3
Poyarka Complex of trachybasalt–rhyolite series	rhyolite	C-723	matrix	120.8	119.4+/–0.4	72	118.7+/–0.4	2.8	298+/–1
	basaltic trachyandesite	C-721	matrix	–	122.2+/–1.5	65	–	–	–
Itikut Complex of andesitic lavas	basaltic trachyandesite	K-517-5	plagioclase	–	125.4+/–3	87	–	–	–
	trachyandesite	C-723-1	plagioclase	112.6	122.8+/–0.8	62	122.4+/–0.3	3.1	284+/–1
			amphibole	123.9	124.4+/–1.8	76	122+/–1.5	3.8	296+/–2
	basaltic andesite	C-725	matrix	119	123.9+/–0.6	57	121+/–2	3.4	298+/–4
Complex of trachyrhyolites	trachyrhyolite	C-791	matrix	139.3	133+/–1.7	58	142+/–1	1.8	418+/–20
	trachyrhyolite	C-792-2	plagioclase	152	136.5+/–1.6	50	134.5+/–1.5	0.9	340+/–7

* Ages are calculated at the confidence level +/–2σ; sample nos. in the table correspond to those in the text and figures.

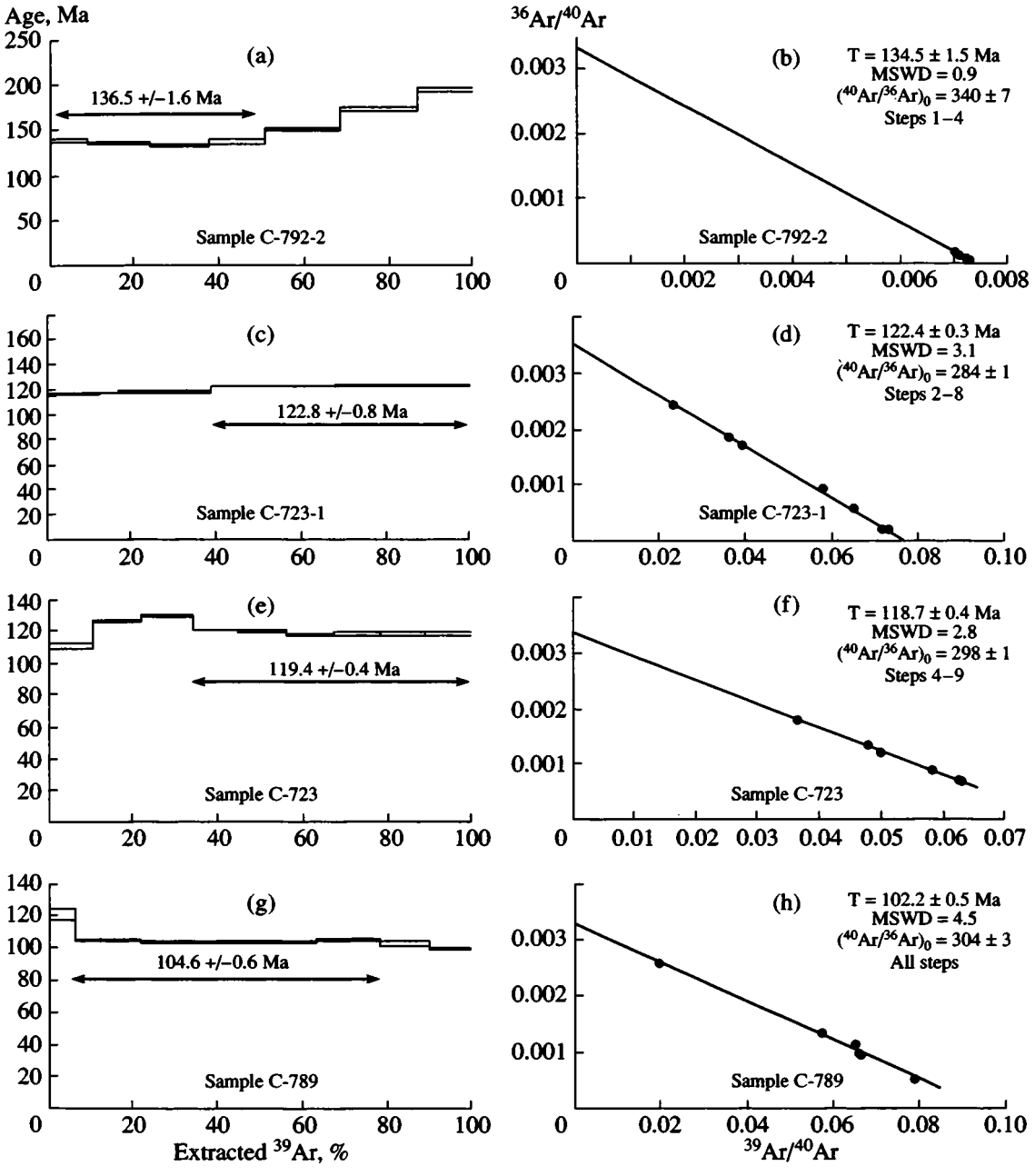


Fig. 3. Thermal annealing (A) and $^{39}Ar/^{40}Ar$ versus $^{36}Ar/^{40}Ar$ (B) diagrams for rock samples from northern and northeastern parts of the Greater Khingan volcano-plutonic belt, the Lesser Khingan Ridge included.

basaltic trachyandesites of the Early Cretaceous Poyarka Complex are enriched to a greater extent in Ba, Rb, Th, Th, light and intermediate REE, being still depleted in Nb, Ta, Ti, heavy REE, and Y (Fig. 6B). The Early–Late Cretaceous trachyandesites of the post-Poyarka time showed higher concentration peaks of Ba and Rb than other volcanic rocks of the study region but lower concentration levels of HFSE and REE than in trachybasalts and rhyolites of the Poyarka Complex (Fig. 6B). The outlined geochemical peculiarities suggest that the Early Cretaceous Poyarka Complex and subsequent post-Poyarka volcanism developed under influence of a mantle magma source enriched in incompatible trace elements.

GEOCHRONOLOGY AND GEOCHEMISTRY OF MAGMATIC ROCKS FROM THE UMLEKAN–OGODZHA BELT

As is shown above, the Umlekan–Ogodzha belt hosts granitoid and volcanic associations of Cretaceous age, which are confined to northern margin of the

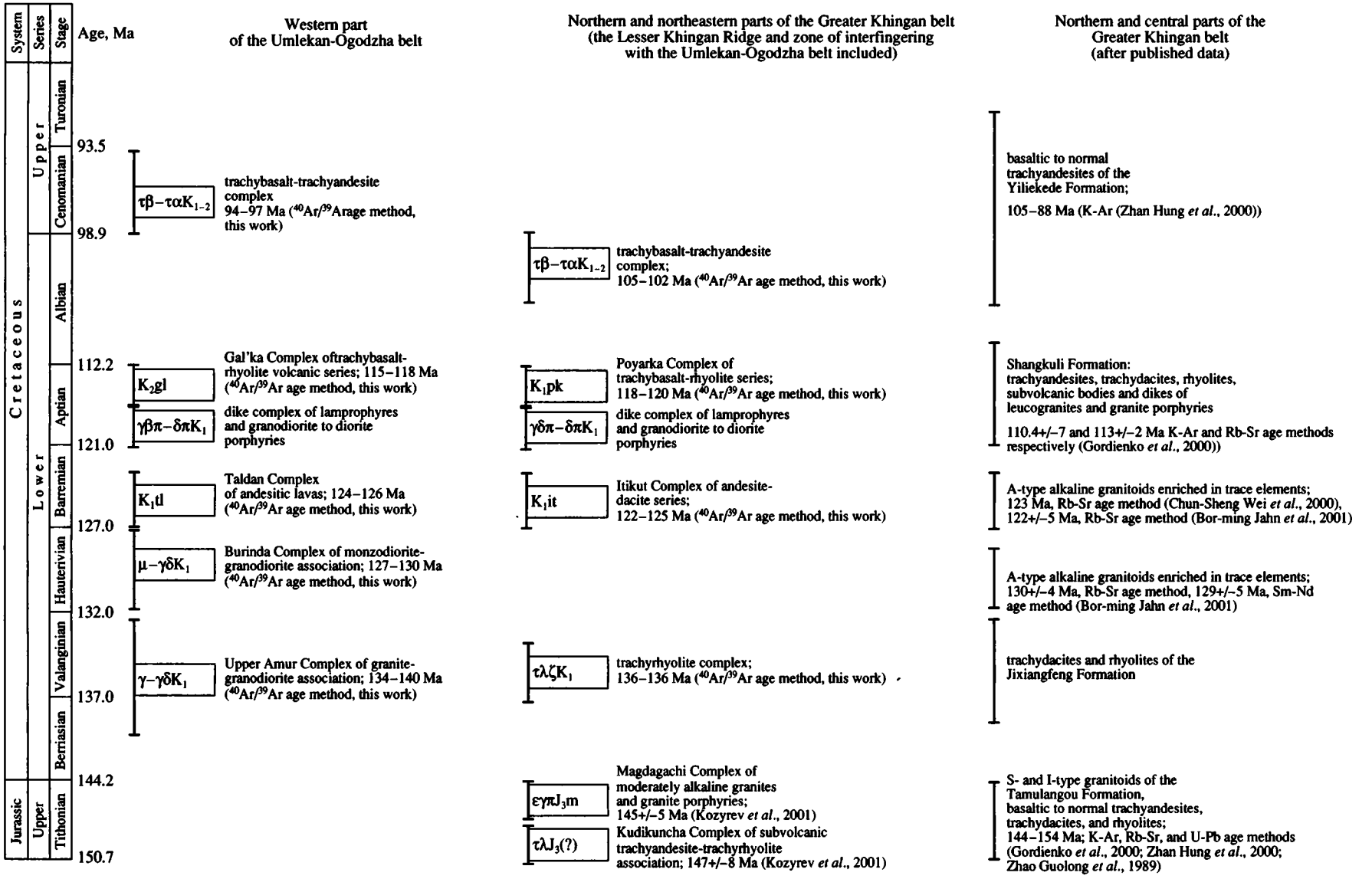

System
Series
Stage
Age, Ma
Western part of the Umlekan-Ogodzha belt
Northern and northeastern parts of the Greater Khingan belt (the Lesser Khingan Ridge and zone of interfingering with the Umlekan-Ogodzha belt included)
Northern and central parts of the Greater Khingan belt (after published data)
Cretaceous
Upper
Lower
Jurassic
Upper
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Tithonian
93.5
98.9
112.2
121.0
127.0
132.0
137.0
144.2
150.7
τβ–ταK1–2
trachybasalt-trachyandesite complex
94–97 Ma (40Ar/39Arage method, this work)
K2gl
Gal'ka Complex oftrachybasalt-rhyolite volcanic series; 115–118 Ma (40Ar/39Ar age method, this work)
γβπ–δπK1
dike complex of lamprophyres and granodiorite to diorite porphyries
K1tl
Taldan Complex of andesitic lavas; 124–126 Ma (40Ar/39Ar age method, this work)
μ–γδK1
Burinda Complex of monzodiorite-granodiorite association; 127–130 Ma (40Ar/39Ar age method, this work)
γ–γδK1
Upper Amur Complex of granite-granodiorite association; 134–140 Ma (40Ar/39Ar age method, this work)
τβ–ταK1–2
trachybasalt-trachyandesite complex;
105–102 Ma (40Ar/39Ar age method, this work)
K1pk
Poyarka Complex of trachybasalt-rhyolite series;
118–120 Ma (40Ar/39Ar age method, this work)
γδπ–δπK1
dike complex of lamprophyres and granodiorite to diorite porphyries
K1it
Itikut Complex of andesite-dacite series;
122–125 Ma (40Ar/39Ar age method, this work)
τλζK1
trachyrhyolite complex;
136–136 Ma (40Ar/39Ar age method, this work)
εγπJ3m
Magdagachi Complex of moderately alkaline granites and granite porphyries;
145+/–5 Ma (Kozyrev et al., 2001)
τλJ3(?)
Kudikuncha Complex of subvolcanic trachyandesite-trachyrhyolite association; 147+/–8 Ma (Kozyrev et al., 2001)
basaltic to normal trachyandesites of the Yiliekede Formation;
105–88 Ma (K-Ar (Zhan Hung et al., 2000))
Shangkuli Formation: trachyandesites, trachydacites, rhyolites, subvolcanic bodies and dikes of leucogranites and granite porphyries
110.4+/–7 and 113+/–2 Ma K-Ar and Rb-Sr age methods respectively (Gordienko et al., 2000))
A-type alkaline granitoids enriched in trace elements;
123 Ma, Rb-Sr age method (Chun-Sheng Wei et al., 2000),
122+/–5 Ma, Rb-Sr age method (Bor-ming Jahn et al., 2001)
A-type alkaline granitoids enriched in trace elements;
130+/–4 Ma, Rb-Sr age method, 129+/–5 Ma, Sm-Nd age method (Bor-ming Jahn et al., 2001)
trachydacites and rhyolites of the Jixiangfeng Formation
S- and I-type granitoids of the Tamulangou Formation, basaltic to normal trachyandesites, trachydacites, and rhyolites;
144–154 Ma; K-Ar, Rb-Sr, and U-Pb age methods (Gordienko et al., 2000; Zhan Hung et al., 2000; Zhao Guolong et al., 1989)

Fig. 4. Age correlation of Mesozoic magmatic complexes, northern margin of the Amurian superterrane.

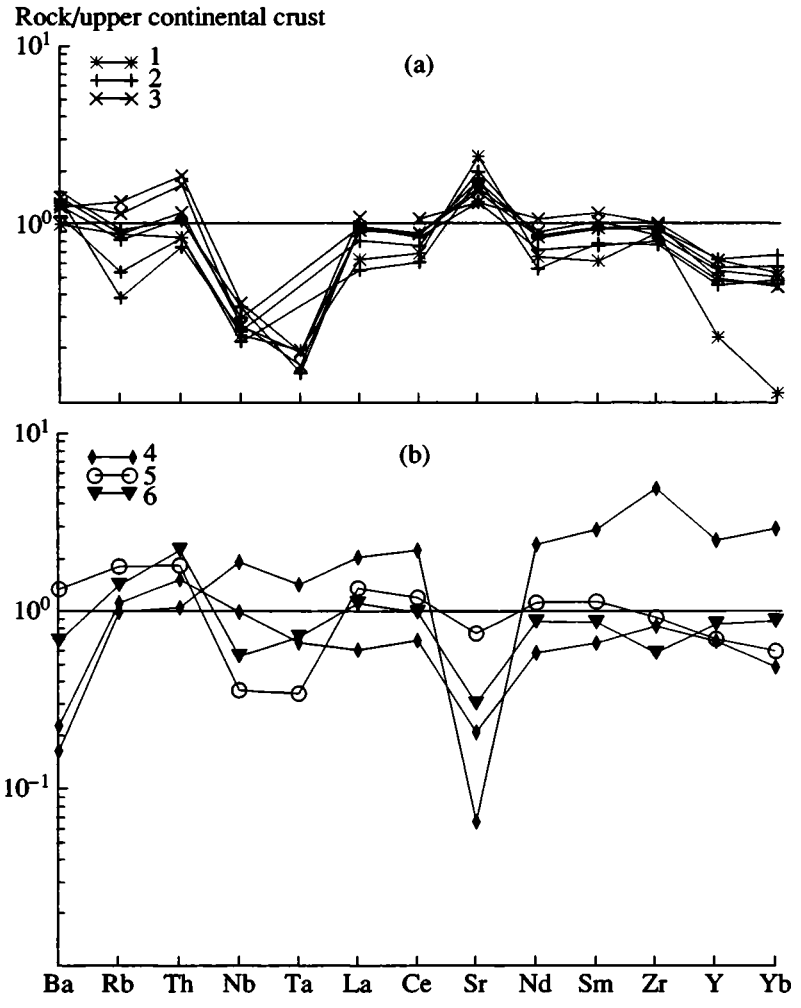


Fig. 5. Multicomponent diagram for Mesozoic granitoids (A) and acid volcanic rocks (B) from northern margin of the Amurian superterrane: (1) Late Jurassic Magdagachi Complex of moderately alkaline granites and granite porphyries; (2) Early Cretaceous Upper Amur Complex of granite–Granodiorite association; (3) Early Cretaceous Burinda Complex of monzodiorite–granodiorite association; (4) Early Cretaceous trachyrhyolites; (5) Early Cretaceous Gal'ka Complex of trachybasalt–rhyolitic lavas; (6) Early Cretaceous Poyarka Complex of trachybasalt–rhyolitic lavas (geochemistry of upper continental crust after Taylor and McLennan, 1988).

Amurian superterrane close to the boundary of the latter with eastern segment of the Mongol–Okhotsk orogenic system. We studied most representative intrusive massifs and volcanic fields of the belt (Fig. 2) to get insight into history and geochemical peculiarities of Mesozoic volcanism and plutonic magmatic activity in this tectonic zone. Nomenclature of magmatic complexes distinguished in the belt is given above, and results of our isotopic–geochronological and geochemical investigations are considered below.

The Early Cretaceous Upper Amur Complex of normal granites and granodiorites is represented by batholiths of a tabular shape and respective petrochemical composition. Granodiorites, quartz diorites, tonalites, and granites prevailing in composition of batholiths occur in association with leucogranites, pegmatites, and aplites of the vein facies. Batholiths intruded the Late Jurassic deposits of the Upper Amur depression and granitoids of the Magdagachi Complex. In turn, intrusions of the Early Cretaceous Burinda Complex cut through the batholiths, which are overlain in places by volcanogenic–sedimentary deposits of the Taldan Formation, which yield fossils of the Barremian–Aptian age.

We established the $^{40}Ar/^{39}Ar$ plateau and concordant isochron (MSWD = 0.7) ages ranging within a narrow interval of 134–140 Ma for mineral phases of granite (Sample K-48-3) and granodiorite (Sample K-1032-4) from the Igak massif (Table, Figs. 7A and 7B). We believe that the above age interval corresponding to the Berriasian–Valanginian of stratigraphic scale (Fig. 4) characterizes the emplacement time of the studied and other massifs of the complex.

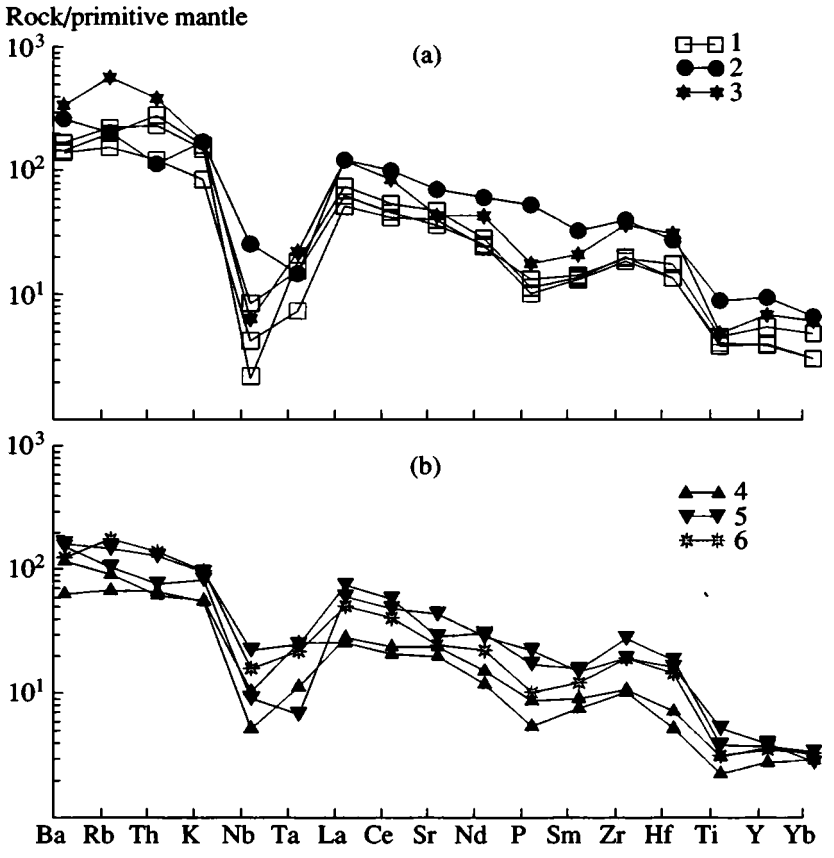


Fig. 6. Multicomponent diagram for Mesozoic for basic to intermediate volcanics from the Umlekan–Ogodzha belt (A) and northern areas of the Greater Khingan belt (B): (1) Early Cretaceous Taldan Complex of andesitic lavas; (2) Early Cretaceous Gal'ka Complex of trachybasalt–rhyolite series; (3) Early–Late Cretaceous complex of trachybasalt–trachyandesite series; (4) Early Cretaceous Itikut Complex of andesite–dacite series; (5) Early Cretaceous Poyarka Complex of trachybasalt–rhyolite series; (6) Early–Late Cretaceous complex of trachybasalt–trachyandesite series (geochemistry of primitive mantle after Sun and McDonough, 1989).

The Early Cretaceous Burinda Complex includes hypabyssal intrusions predominantly composed of alkaline monzodiorites and granodiorites and of quartz monzonites, diorites, and granodiorites. Intrusions of this composition are variable in shape, from dikes to large lopoliths. According to geological data, rocks of the complex are in eruptive relations with granitoids of the Upper Amur Complex, being overlain in turn by andesitic lava flows of the Barremian–Aptian Taldan Formation. Accordingly, it was inferred that the emplacement period of intrusions corresponds to the Hauterivian–Barremian interval.

Concordant plateau ages of 130.2 ± 1.3 (biotite) and 127.2 ± 0.9 Ma (whole rock) have been established, along with consistent isochron ages (MSWD from 0.4 to 1.3), for granodiorites of the Dzhiktanda massif (Sample K-294) and for quartz diorites of the Magdagachi massif (Sample K-311) (Table, Figs. 7C and 7D). Monzonites of the former massif (sample K-291-3) turned out to be older, as they yielded plateau age of 142.2 ± 1.6 Ma, and isochron age of 141.6 ± 3.3 Ma (MSWD = 0.61). The last values appear to be closer to the formation time of the Upper Amur Complex considered above (Fig. 4).

The Early Cretaceous Taldan Complex comprises a series of central-type volcanoes, characteristic of which was a mixed explosive–eruptive regime of volcanic activity. Amphibole to biotite–amphibole andesites, dacitic andesites, dacites and their tuffs associated with less frequent trachyandesites and basaltic andesites are the main rock types of the complex.

The Barremian–Aptian age of the complex is established based on found species *Limnocyrena sibirica* (Ramm.), *Leptesthes elongatus* Mart., *Unio* cf. *obrutschevi* Mart., *U. elongatus* Mart., and *U.* ex gr. *pseudomargaritana* Mart. representing freshwater mollusks and on plant remains *Coniopteris nympharum* (Heer) Vachr., *C. arctica* (Pryn.) Samyl., and others from sediments intercalated with lavas (*Resolutions...*, 1994). The analyzed dacitic andesite (Sample K-290-1) and basaltic andesite (Sample C-703) from the Taldan and Ablyukun volcanic fields yielded concordant plateau and isochron (MSWD from 0.6 to 1.9) ages ranging from 123 to 127 Ma (Table, Figs. 7E and 7F). This period corresponding to the Barremian in stratigraphic

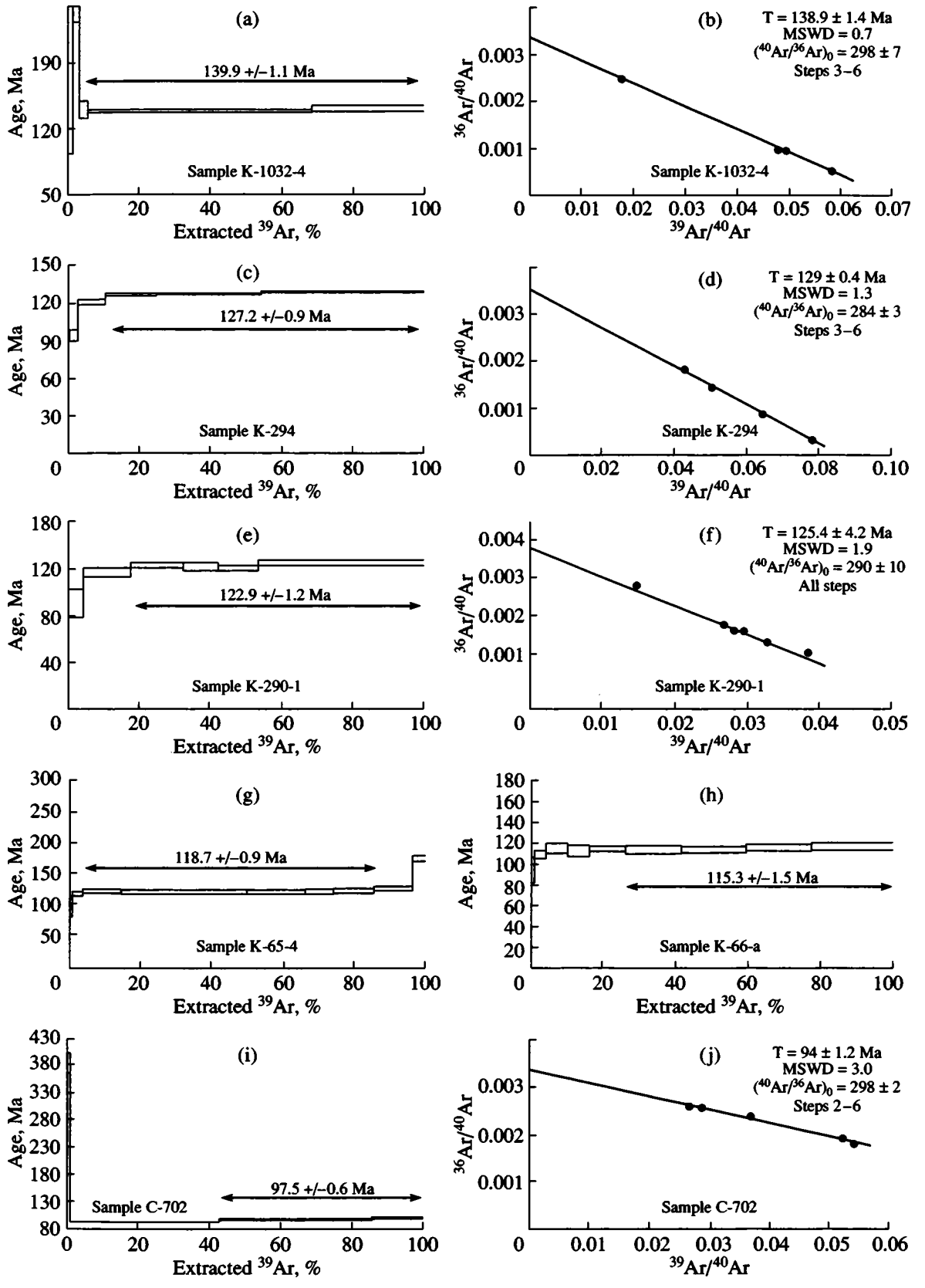


Fig. 7. Thermal annealing (left) and $^{39}Ar/^{40}Ar$ versus $^{36}Ar/^{40}Ar$ (right) diagrams for rock samples from western areas of the Umlekan–Ogodzha volcano–plutonic belt.

scale (Fig. 4) characterizes, as we think, the formation time of the complex.

The Early Cretaceous Gal'ka Complex corresponds to small lava fields of trachybasalts, basaltic trachyandesites, trachyandesites, trachydacites, and normal to trachytic rhyolites. Predominant basic and acid rock varieties determine the bimodal type of the entire association. Among trachybasalts, there are varieties with plagioclase and orthopyroxene phenocrysts.

Age interpretation of the Gal'ka Complex is controversial. Interlayer of ashy tuffs and tuffaceous aleurites yield fossil bivalves *Lamproscapha elliptica* Marth., *L. lanceolate* Marth., *Leptesthes coreanica* (Kob. et Suz.), and *Sainshandia* sp. associated with conchostracans *Leptolimnadia (?)* aff. *mongolica* Novoj., *Trogonlimnadia (?) trogonodes* Novoj., *Limnadia* sp., and *Paleoletestheria* sp. These fossils are of the Cenomanian to late Cenomanian–Santonian age that is consistent with the dates of 94.5 ± 1.9 and 97 ± 5 Ma obtained respectively for rhyolites and perlites of the Gal'ka stratotype volcanic field and for trachydacites and rhyolites of the Kovrizhkino field, which have been dated by Rb–Sr method at the All-Russia Research Institute of Geology (Kozyrev *et al.*, 2001).

In this work, we analyzed matrix fractions of trachybasalt (Sample K-65-4) and rhyolite (Sample K-66-a) from the same Gal'ka field and determined the $^{40}Ar/^{39}Ar$ ages corresponding to 118.7 ± 1.8 and 115.3 ± 1.5 Ma respectively (Table, Figs. 7G and 7H). These results are consistent with the U–Pb age of 117 ± 1 Ma obtained for rhyolite from the Kovrizhkino field at the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, St. Petersburg (Kozyrev *et al.*, 2001). The concordant age values obtained by $^{40}Ar/^{39}Ar$ and U–Pb age methods considerably differ from results of the Rb–Sr dating of rocks from the same volcanic field, and these results should be revised as we think. In our opinion, lava eruptions in the Gal'ka volcanic field took place most likely 115–119 Ma ago (Fig. 4).

The Early–Late Cretaceous trachybasalt–trachyandesite complex is distinguished for the first time among the rocks, which were formerly included into the Gal'ka Complex considered above, as they are close in composition to trachybasalts and trachyandesites of the latter.

Using the $^{40}Ar/^{39}Ar$ age method, we dated amphibole fraction of trachyandesite (Sample C-702) from the Ulunga volcanic field and got the plateau and close isochron (MSWD = 3.0) ages of 97.5 ± 0.6 and 94.0 ± 1.2 Ma respectively (Table, Figs. 7I and 7J). In our opinion, fossils from sediments intercalated with volcanics (see above) characterize this but not the Gal'ka Complex of trachybasalt–rhyolite composition, as it was suggested earlier (Kozyrev *et al.*, 2001).

As it follows from dating results considered above, Mesozoic magmatic rocks of the western Umlekan–Ogodzha belt are divisible into the granite–granodiorite Upper Amur (134–140 Ma), monzodiorite–granodiorite Burinda (127–130 Ma), andesite Taldan (124–126 Ma), and trachybasalt–rhyolite Gal'ka (115–119 Ma) complexes of the Early Cretaceous, which antedated eruptions of trachybasalt–trachyandesite composition at the Early–Late Cretaceous boundary time 94–97 Ma ago. In the scheme presented in Fig. 4, there is shown one more complex of the post Taldan time, which includes the Early Cretaceous dikes of granodiorite and diorite porphyries. This complex is shown conventionally, because respective rocks have not been reliably dated by isotopic methods.

According to bulk chemical and geochemical composition, the Early Cretaceous intrusive rocks of the belt are comparable with the I- and S-type granitoids. Concentrations of Ba, Rb, Th, and Zr in these rocks are at the level typical of the upper continental crust. In addition, they are distinctly depleted in REE, Nb, and Ta, being enriched in Sr (Fig. 5A). These geochemical peculiarities are characteristic of granitoids of active continental margins.

As one can see from spider diagram (Fig. 6A), andesitic volcanics of the Early Cretaceous Gal'ka Complex are enriched relative to the primitive mantle in Ba, Rb, Th, K, Sr, light to intermediate REE and show concentration minimums of Nb, Ta, P, Ti, and Y. According to these characteristics, the respective volcanism could be of a suprasubduction origin.

A relatively higher level of REE and HFSE concentrations is characteristic of the Early Cretaceous Gal'ka Complex of trachybasalt–rhyolite composition and of the Early–Late Cretaceous trachybasalts and trachyandesites. The negative Nb-, Ta-, and Ti-anomalies are less prominent in these rocks (P-anomaly is absent) in distinction from older Early Cretaceous andesites of the Taldan Complex (Fig. 6A).

CORRELATION OF MESOZOIC MAGMATIC EVENTS IN THE UMLEKAN–OGODZHA AND GREATER KHINGAN BELTS

The new and formerly published dating results elucidate to a certain extent the particular stages of magmatic activity in central to northern and northeastern areas of the Greater Khingan belt and in western areas of the Umlekan–Ogodzha belt. It is not so easy however to correlate magmatic events distinguishable in separate areas because of controversial viewpoints on geology of central areas in the Greater Khingan orogenic system that is a consequence of the outdated and incorrect age determinations as shown by Chinese geologists (Zhan Hung *et al.*, 2000; Fu-yuan Wu *et al.*, 2000).

Our analysis of available geochronological and geochemical information showed that there were correlative and distinctive events in the Mesozoic evolution of the belts under comparison. These events characterizing successive geological stages are considered below.

Late Jurassic. An intense volcanic (Tamulangou Formation) and intrusive (I- and S-type granitoids) activity of this period produced rocks, which constitute the main volume of the Greater Khingan belt. In the Amur River upper courses corresponding to the extreme northeastern flank of the belt, respective volcanic and intrusive rocks are represented by the late Jurassic Kudikuncha Complex of trachyandesite–trachyrhyolite composition and by moderately alkaline granites and granite porphyries of the Magdagachi Complex (Fig. 4). Reliable data on development of the Late Jurassic magmatic activity further eastward along the northern margin of the Amurian superterrane are unknown so far.

Initial Early Cretaceous. In the Greater Khingan belt, this stage (Fig. 4) resulted in formation of alkaline acid volcanics (Jixiangfeng Formation) and alkaline A-type granitoids enriched in trace elements (Chun-Sheng Wei *et al.*, 2000; Fu-yuan Wu *et al.*, 2000; Bor-ming Jahn *et al.*, 2001). These rocks are distinct from concurrent calc-alkaline granitoids of the Upper Amur and Burinda complexes and from andesites of the Taldan Complex, which are widespread in the Umlekan–Ogodzha belt (Fig. 4).

As is mentioned above, structural boundary between two belts is indistinct. In a certain sense, the region of the Amur River upper courses corresponds to a zone, where the belts are superimposed, since granite–granodiorite intrusions of the Early Cretaceous Upper Amur Complex of the Umlekan–Ogodzha belt cut here through the moderately alkaline granites and granite porphyries of the Late Jurassic Magdagachi Complex, which are attributed to the Greater Khingan belt. A similar situation is observable in the northeastern flank of the Lesser Khingan Ridge, where the Early Cretaceous trachyrhyolites of the Greater Khingan belt are closely associated in space with concurrent calc-alkaline andesites and dacites of the Itikut Complex. In its composition and age, the latter is likely an equivalent of the Early Cretaceous Taldan Complex of the Umlekan–Ogodzha belt (Fig. 4).

Early–Late Cretaceous boundary time. In most areas of the Greater Khingan belt, magmatism almost ceased at this time. The respective volcanic activity in northern areas of the belt produced lavas of trachyandesite–trachydacite–rhyolites series of the Early Cretaceous Shangkuli Formation and associated subvolcanic bodies and dikes of leucogranites and granite porphyries, and then, at the terminal Early–initial Late Cretaceous time, it led to eruptions of basaltic to normal trachyandesites of the Yiliekide Formation. In the northeastern Greater Khingan belt (Russian areas of the Lesser Khingan Ridge), analogous rocks belong, as we think, to the Early Cretaceous Poyarka Complex of the bimodal trachybasalt–rhyolite type and to the Early–Late Cretaceous complex of trachybasalt–trachyandesite composition (Fig. 4). Identical magmatic formations of the western Umlekan–Ogodzha belt are represented by trachybasalt–rhyolite volcanic series of the Early Cretaceous Gal'ka Complex and by the Early–Late Cretaceous lavas of trachybasalt–trachyandesite composition (Fig. 4).

CONCLUSION

Main conclusions from the considered data are as follows:

1. General trend of magmatism development in the Greater Khingan and Umlekan–Ogodzha belts was similar or even identical. In both belts, the early calc-alkaline magmatic associations (I- and S-type granitoids and predominantly andesitic volcanic series) were replaced with time by subalkaline to alkaline associations (bimodal and alkali-basalt volcanic series).

2. Magmatic associations of similar composition originated in two belts during different geological periods. The calc-alkaline magmatism of the Greater Khingan belt is of the Late Jurassic age, while comparable magmatic associations of the Umlekan–Ogodzha belt originated in the initial Early Cretaceous. The aforementioned transition from calc-alkaline to alkaline magmatic activity was also asynchronous in two belts, as it took place at the commencement and at the end of the Early Cretaceous period respectively.

3. The Early Cretaceous A-type granitoids widespread in the Greater Khingan belt ((Chun-Sheng Wei *et al.*, 2000; Fu-yuan Wu *et al.*, 2000; Bor-ming Jahn *et al.*, 2001) are absent in the Umlekan–Ogodzha belt.

Thus, the asynchronous development of magmatism in the Greater Khingan and Umlekan–Ogodzha belts, until the mid-Early Cretaceous time at least, is obvious, excluding a possibility to consider the belts as parts of an integral structural zone. Accordingly, it is possible to assume that the belts under discussion developed independently from each other until the indicated time moment. Otherwise, we should postulate a progressive displacement of magmatic activity in the north-northeastern direction during development of hypothetical integral structure.

The younger subalkaline to alkaline magmatic associations (bimodal and alkali-basalt volcanic series) of the Umlekan–Ogodzha and northern Greater Khingan belts greatly differ in geochemical parameters from older intrusive and volcanic rocks and likely represent associations superimposed on older, already consolidated structures of both belts. Pertaining of the younger rocks is a geochemical signature of the intraplate magmatic activity.

ACKNOWLEDGMENTS

We are grateful to S.I. Dril' for his valuable advices and to V.V. Yarmolyuk and M.M. Arakelyants for criti-

cal remarks to the manuscript. The work was jointly supported by the Presidium of the Far East Division, Russian Academy of Sciences (project no. 24), Russian Foundation for basic Research (project no. 03-05-64533), and by the Committee of Nature Management and Mining Complex, Amur Oblast Administration (contract no. 00-3-166).

Reviewers V.V. Yarmolyuk and M.M. Arakelyants

REFERENCES

1. Bor-ming Jahn, Fuyuan Wu, R. Capdevila, *et al.*, "Highly Evolved Juvenile Granites with Tetrad REE Patterns: the Woduhe and Baerzhe Granites from the Great Xing'an Mountains in the NE China," Lithos **59**, 171–198 (2001).
2. R. J. Fleck, J. F. Sutter, and D. H. Elliot, "Interpretation of Discordant 40Ar/39Ar Age Spectra of Mesozoic Tholeiites from Antarctica," Geochim. Cosmochim. Acta **41**, 15–32 (1977).
3. Fu-yuan Wu, Bor-Ming Jahn, S. Wilde, and De-you Sun, "Phanerozoic crustal growth: U–Pb and Sr–Nd Isotopic Evidence from the Granites in Northeastern China," Tectonophysics **328**, 89–113 (2000).
4. *Geological Map of the Near-Amur and Adjacent Areas, Scale 1 : 2500000, Explanatory Notes* (Ministry of Natural Reserves RF, St. Petersburg, 1999) [in Russian].
5. *Geology of the BAM Zone* (Nedra, Leningrad, 1988), Vol. 1 [in Russian].
6. I. V. Gordienko, V. S. Klimuk, and Q. Heng, "The Upper Amur Volcano-Plutonic Belt of Eastern Asia," Geol. Geofiz. **41** (12), 1655–1669 (2000).
7. I. V. Gordienko, V. S. Klimuk, and Q. Heng, in *Proceedings of the 3rd Symposium on Geological and Minerageneticic Correlation in the Contiguous Regions of China, Russia and Mongolia, Changchun, China, 1999*, p. 2.
8. G. S. Gusev and V. E. Khain, "Relationships between the Baikal–Vitim, Aldan–Stanovoi and Mongol-Okhotsk Terranes (the South of Central Siberia)," Geotektonika, No. 5, 68–82 (1995).
9. L. B. Gustafson, W. Orquera, M. Mcwillian, *et al.*, "Multiple Centers of Mineralization in the Indio Muerto District, El Salvador, Chile," Econ. Geol. **96**, 325–350 (2001).
10. A. I. Khanchuk, "Paleogeodynamic Analysis of Ore Deposits in the Russian Far East," in *Ore Deposits in Continental Margins* (Dal'nauka, Vladivostok, 2000), pp. 5–34 [in Russian].
11. V. I. Kovalenko, V. V. Yarmolyuk, V. P. Kovach, *et al.*, "Magmatism as Factor of Crust Evolution in the Central Asian Foldbelt: Sm-Nd Isotopic Data," Geotektonika, No. 3, 21–41 (1999) [Geotectonics **33**, 191–208 (1999)].
12. S. K. Kozyrev, Yu. R. Volkova, N. N. Ignatenko, *et al.*, *State Geological Map of Russian Federation, Scale 1 : 200 000, Sheet N-51-XXIV, Explanatory Notes* (VSEGEI, St. Petersburg, 2001) [in Russian].
13. *Magmatic Rocks, Vol. 6: Evolution of Magmatism in the Earth's History* (Nauka, Moscow, 1987) [in Russian].
14. M. V. Martynyuk, S. A. Ryamov, and V. A. Kondrat'eva, *Explanatory Notes to the Chart of Correlation of Magmatic Complexes in the Khabarovsk Krai and Amur Oblast* (PGO Dal'geologiya, Khabarovsk, 1990) [in Russian].
15. V. G. Moiseenko and V. G. Sakhno, *Mantle-Plume Magmatism and Minerageny of the Amur Megastructure* (AmurKNII, Blagoveshchensk, 2000) [in Russian].
16. L. M. Parfenov, *Continental Margins and Mesozoic Island Arcs in Northeastern Asia* (Nauka, Novosibirsk, 1984) [in Russian].
17. L. M. Parfenov, L. I. Popeko, and O. Tomurtogoo, "Problems of Tectonics in the Mongol–Okhotsk Orogenic Belt," Tikhookean. Geol. **18** (5), 24–43 (1999).
18. J. A. Pearce, N. B. W. Harris, and A. G. Tindle, "Trace Element Discrimination of Granitic Rocks," J. Petrol. **25**, Pt. 4, 956–983 (1984).
19. V. A. Ponomarchuk, Yu. N. Lebedev, A. V. Travin, *et al.*, "Application of Fine Magnetic Separation in K–Ar, ^{40}Ar–^{39}Ar, and Rb–Sr Dating of Rocks and Minerals," Geol. Geofiz. **39** (1), 55–64 (1998).
20. *Resolutions of the IV Interdepartmental Regional Stratigraphic Conference on the Precambrian and Phanerozoic of the Southern Far East and Eastern Transbaikal Region, a Set of Schemes* (Khabarovsk State Enterprise of Mining Geology, Khabarovsk, 1994) [in Russian].
21. D. O. Shevchenko, V. A. Ponomarchuk, and V. V. Manoilov, "Excel Macros to Process the Ar–Ar Data," in *Isotopic Dating of Geological Processes: New Methods and Results, Proceedings of Scientific Conference, Moscow, November 15–17, 2000* (GEOS, Moscow), pp. 408–411 [in Russian].
22. Yu. F. Sidorov, *State Geological Map of the USSR, Scale 1 : 200000, Amur–Zeya Series, Sheets M-52-VII and M-52-VIII* (Nedra, Moscow) [in Russian].
23. A. P. Sorokin, *State Geological Map of the USSR, Scale 1 : 200000, Amur–Zeya Series, Sheet M-52-I, Explanatory Notes* (Nedra, Moscow, 1975) [in Russian].
24. A. P. Sorokin, *State Geological Map of the USSR, Scale 1 : 200000, Amur–Zeya Series, Sheet M-52-II, Explanatory Notes* (Nedra, Moscow, 1975) [in Russian].
25. A. A. Sorokin and V. A. Ponomarchuk, "Umlekan-Ogodzha Early Cretaceous Magmatic Belt (North Margin of the Amurian Superterrane): Duration of Magmatism," Geochim. Cosmochim. Acta **66** (15A), 728 (2002a).
26. A. A. Sorokin and V. A. Ponomarchuk, *Continental Growth in the Phanerozoic: Evidence from Central Asia. Abstract and Field Guidebook of IGCP420 IV Workshop, Changchun, August 5-14, 2002*, Ed. by Fu-yuan Wu, S. A. Wilde, and B.-M. Jahn (Changchun, 2002b) pp. 97–100.
27. S. S. Sun and W. F. McDonough, "Chemical and Isotopic Systematics of Oceanic Basalts: Implication for Mantle

Composition and Processes," in *Magmatism in the Ocean Basins* (Blackwell, London, 1989) pp. 313–346.

28. S. R. Taylor and S. M. McLennan, *The Continental Crust: Its Composition and Evolution* (Blackwell, Oxford, 1985; Mir, Moscow, 1988).
29. *Volcanic Belts of Eastern Asia*, Ed. by A. D. Shcheglov (Nauka, Moscow, 1984) [in Russian].
30. Wei Chun-Sheng, Zheng Yong-Fei, and Zhao Zi-Fu, "Hydrogen and Oxygen Isotope Geochemistry of A-Type Granites in the Continental Margins of Eastern China," J. South Am. Earth Sci. **328**, 205–227 (2000).
31. V. V. Yarmolyuk, V. I. Kovalenko, and M. I. Kuz'min, "North Asian Superplume Activity in the Phanerozoic: Magmatism and Geodynamics," Geotektonika, No. 5, 3–29 (2000) [Geotectonics **34**, 343–366 (2000)].
32. V. V. Yarmolyuk, V. I. Kovalenko, and V. G. Ivanov, "The Late Mesozoic–Cenozoic Intraplate Volcanic Province in Central East Asia – Projections of Mantle Hot Spots," Geotektonika, No. 5, 41–67 (1995).
33. Zhan Hung *et al.*, "Dynamic Background of Mesozoic Volcanism in Northern Areas of the Greater Khingan Ridge," Tikhookean. Geol. **19** (1), 109–117 (2000).
34. Zhao Guolong, Yang Guilin, Fu-jiayou, and Yang Yuzuo, *The Mesozoic volcanic rocks in Middle and Southern Parts of Daxing Anling Range* (Science and Technology Publishing House, Beijing, 1989).
35. L. P. Zonenshain, M. I. Kuz'min, and L. M. Natapov, *Plate Tectonics of the USSR* (Nedra, Moscow, 1990) [in Russian].

Stratigraphy and Geological Correlation, Vol. 12, No. 6, 2004, pp. 588–602. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 12, No. 6, 2004, pp. 53–68.
Original Russian Text Copyright © 2004 by Makulbekov.
English Translation Copyright © 2004 by MAIK "Nauka/Interperiodica" (Russia).

Stratigraphic Position of the Albian and Late Cretaceous Floras in Southern Mongolia

N. M. Makulbekov

Paleontological Institute, Russian Academy of Sciences, Moscow

Received March 20, 2003; in final form, July 15, 2003

Abstract—First data on the Late Cretaceous floras occurring in association with diverse invertebrate and vertebrate faunas at 11 localities of southern Mongolia are reported. Ages and stratigraphic position of studied plant remains and taphocoenoses as a whole are determined based on succession of faunal and floral assemblages. Composition of Albian to Maastrichtian floras is analyzed. Based on dominant taxa, the Aptian–Albian, Cenomanian–Turonian, Campanian, and Maastrichtian assemblages are distinguished. Late Cretaceous landscapes and climatic conditions of vertebrate habitats in the southern Gobi are reconstructed.

Key words: southern Gobi, Barun-Bayan, Bain-Shire, Barun-Goiot and Nemegt formations, taphocoenosis, fauna, flora, charophytes.

At present, geologists and paleontologists distinguish the Barun-Bayan, Bain-Shire, Barun-Goiot, and Nemegt formations in the Albian and Upper Cretaceous sediments of southern Mongolia. Below is a brief lithological and paleontological characterization of these units.

Barun-Bayan Formation (Aptian–Albian). Until recently volcanogenic–sedimentary sequences of the Dzun-Bayan and Barun-Bayan sites were referred to the Cenomanian or Albian–Cenomanian Sain-Shanda Formation (Turishchev, 1955; Vasil'ev *et al.*, 1977; Martinson *et al.*, 1969; Nagibina *et al.*, 1977). Remains of typical Lower Cretaceous dinosaurs found in the uppermost part of the formation exposed at Mt. Khara-Khutul-Ula (Martinson *et al.*, 1969) suggest along with other records that respective sediments are older than the Albian–Cenomanian in age. Based on these data, N.N. Verzilin inferred that it is unreasonable to discriminate the Sain-Shanda Formation in this and other areas of the southern Gobi. Being of the same viewpoint, Shuvalov (1982) renamed the unit into the Barun-Bayan Formation. Characteristic of the formation is frequent occurrence of coarse clastic rocks in combination with gray-colored and variegated sediments. Red beds of the Barun-Bayan Formation overlie with a hiatus and often unconformably the older Mesozoic sediments, the Aptian–Albian (Nagibina *et al.*, 1977) gray-colored Kukhtyk Horizon included, almost everywhere in Mongolia. They are in a conformable contact with the lower Cenomanian–Turonian part of the Bain-Shire Formation.

The upper and lower boundaries of the Barun-Bayan Formation are most distinct at the Tsogt-Obo, Dzun-Bayan, and Barun-Bayan sites in the south of the northern Gobi. Sediments of the formation unconformably overlie the gray fauna-bearing sandstones and clays of the Aptian–Albian Khulsyn-Gol Formation (Shuvalov, 1975), being conformably overlain by gray deposits of the Bain-Shire Formation. The formation is about 200 m thick in total. Its flora-bearing bed yields remains of ostracodes, mollusks, charophytes, and dinosaurs. The Barun-Bayan Formation is known in other areas of the northern and southern Gobi as well. In the Ulan-Osha area, it contains bone remains of small Ankylosauridae (Maleev, 1952) and teeth of Theropoda, small Iguanodontidae, and Psittacosauridae (Shuvalov, 1975; Sochava, 1975). In the Ologoi-Ulan-Tsav section, bones of Sauropoda and numerous clutches of large (up to 10 cm across) dinosaur eggs, likely of Sauropoda, were found (Sochava, 1975). In the Trans-Altai Gobi, the Barun-Bayan Formation is exposed in the Dushi-Ula Mountains: on northern and eastern slopes of Mt. Ongon-Ulan-Ula Mountain, on northern and southern slopes of Mt. Altan-Ula, and in northern foothills of the Tost-Ula Range. Rocks of the formation occur as well in the adjacent Shiregin-Gashun depression and the Arts-Bogd Range. In the Ologoi-Tsav depression, south of Dushi-Ula, intact clutches of dinosaur and turtle eggs were encountered. Bones of Psittacosauridae and Iguanodontidae found in the Khara-Khutul-Ula section which likely indicate the Aptian–Albian age of their host rocks, since Psittacosauridae remains are unknown from the Upper Cretaceous sediments of Mongolia and other regions of Central Asia and North America. To the northeast of the Shine-Bulak spring, the Manlai Lake area, G.M. Bratseva distinguished palynological assemblages in Bed 12 of the Barun-Bayan Formation (Lopatin, 1980), which are characteristic of the Lower Cretaceous sediments in Mongolia. The assemblages are represented by *Inaperturopolleni-*

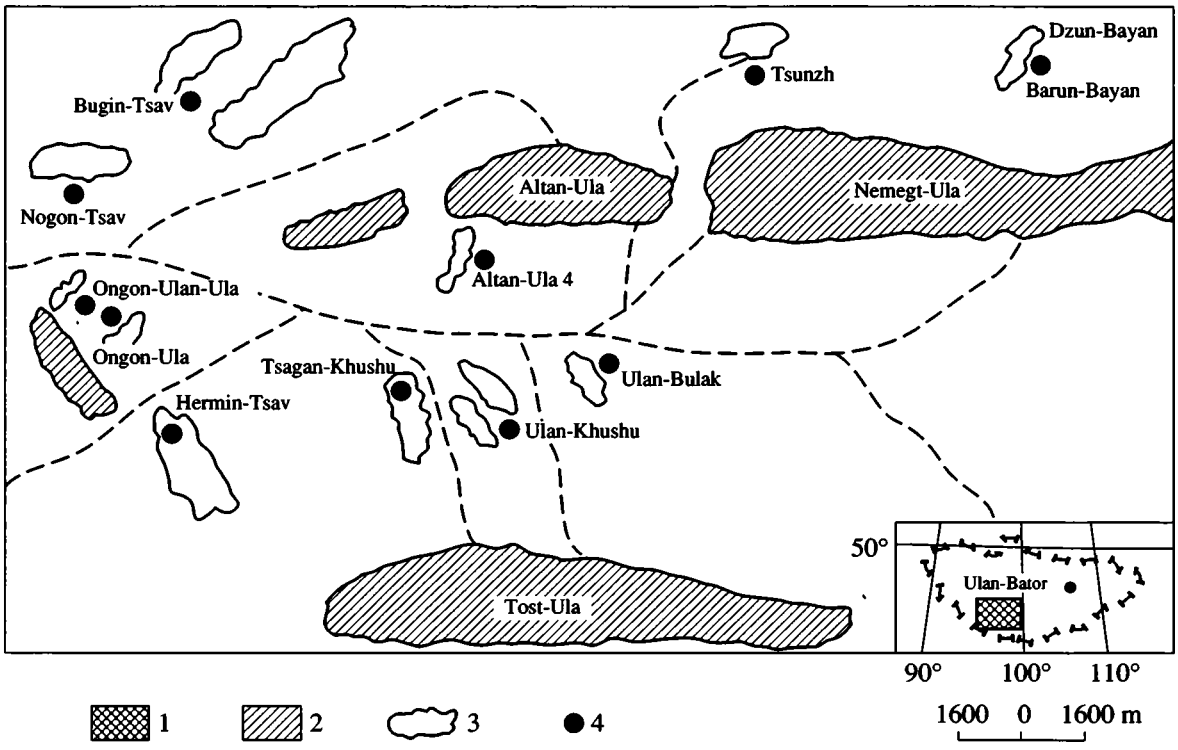
tes sp., *Ginkgocycadophytus* sp., *Coniferalis, Cyathidites* sp., *Plicifera* sp., *Foraminisporites wothaggiensis* (Cook. et Dett.) Dett., *F.* sp., *Cicatricosisporites dorogensis* Pot. et Gell., *C. minuta striatus* (Bloch) Pocock, *C. australiensis* (Cook.) Potonie., *C. ludbrookii* Dett., *C.* sp., *Leiotriletes* sp., *Appendicisporites triconitatus* Weyland and Greifeld, *Gigatricosis ludbrooki* Dett., *Trilobosporites* sp., *Baculatisporites comaumensis* (Cook.) Potonie, *Leptolepidites major* Couper., *Pilosisporites trichopapillosus* Dal. et Sprum., and *Klukisporites* sp.

Charophytes from the Barun-Bayan Formation were found at the Dzun-Bayan, Ologoi-Ulan-Tsav, and Tsagan-Khairkhan-Ula localities (Kyansep-Romashkina, 1982). They are represented by *Mesochara sainshandica* Kyansep-Rom., *M. tuzsoni* (Rasky) Kyansep-Rom., and *Atopochara trivolvis* Peck. The most widespread taxon is *M. sainshandica* from in the Barun-Bayan strata at the Dzun-Bayan site of northern Gobi (Kyansep-Romashkina, 1975). The species was also encountered in the Bain-Shire and Barun-Goiot formations of the southern Gobi. According to morphologic characters, it is similar to *Aclistochara mundula* Peck and *Porochara mundula* (Peck) Zhen from the Lower Cretaceous of North America and China (Peck, 1957; Zhen Wang, 1978). *Mesochara tuzsoni* is typical of the Aptian in Hungary, while *Atopochara trivolvis* is characteristic of this stage in North America and of the Lower Cretaceous sediments in North and South America, Western Europe, northern Africa, and Central Asia (Peck, 1957; Rasky, 1945; Bellen, 1948; Kyansep-Romashkina, 1969, 1974; Musacchio, 1979).

Thus, *Mesochara tuzsoni* and *Atopochara trivolvis* present in charophyte assemblage of the Barun-Bayan Formation are typical of the Early Cretaceous, whereas *Mesochara sainshandica* existed in Mongolia until the Maastrichtian. Based on charophyte taxa, the Barun-Bayan Formation of southern Mongolia can be referred with confidence to the Albian. Charophytes also suggest that lakes in Mongolia were at that time very similar to the Early Cretaceous lakes of Siberia, being rather deep and comparatively cold (Kyansep-Romashkina, 1982).

Paleontological records summarized above strongly suggest the Aptian–Albian age of the Barun-Bayan Formation. The encountered floral remains do not contradict this conclusion as well.

The Dzun-Bayan flora was found in the Barun-Bayan Formation of northern Gobi westward of the Tsogt-Obo site in 1986 by S.M. Sinitsa from Chita, a participant of paleoentomological expedition organized by the Paleontological Institute, RAS (figure). In this flora, I identified ferns *Onychyiopsis psilotoides* (Stokes et Webb) Ward, Ginkgoales *Ginkgo* ex gr. *adiantoides* (Ung.) Heer, conifers *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Araucarites* sp., *Athrotaxopsis grandis* Font., *Sequoia microlepis* Sveshn., a new angiosperm genus and species, and leaves of monocotyledons identified as *Phyllites* sp. and *Graminophyllum* sp. Among this plant assemblage, ferns are scarce in the flora, while dominant conifers are mostly represented by numerous leafy shoots of *Athrotaxopsis grandis*, which are very similar to that of *A. expansa* Font. from the Lower Cretaceous of southern Primorie (Krasilov, 1967). Small angiosperm leaves with venation of uncertain type are common. Such leaves characteristic of the Aptian–Albian floras of Asia and North America (Doyle and Hickey, 1972; Hickey and Doyle, 1977; Krassilov, 1967, 1977, 1989b; Samylina, 1976; Vakhrameev, 1988) are referred by Krassilov (1979, 1989b) to the *Laurifolia* and *Legumifolia* morphotypes of the formal classification system. According to the natural classification (Takhtadzhyan, 1970), they correspond to modern and extinct genera *Lindera, Platanus, Cissites*, and *Cinnamomoides* (Samylina, 1976). The reported list of taxa is preliminary, based on a moderate number of plant imprints from the above locality, and the actual diversity of the Aptian–Albian Dzun-Bayan flora cannot be evaluated therefore. Judging from dominant taxa, it is most similar to the Aptian–Albian Omsukchan flora from the coal field on the Kolyma River right bank in northeastern Asia (Samylina, 1976). According to stratigraphic position, it may be correlative with the Aptian–Albian plant assemblages of the Khulsun-Gol (Bon-Tsagan flora) and Anda-Khuduk (Bon-Tsagan, 87, Kholbotu-Gol, Erdeni-Ula, and Shin-Khuduk floras) formations of southwestern central Mongolia (Krassilov, 1982). However, the Dzun-Bayan flora has a little in common with these assemblages. Similar features consist in occurrence of some fern, conifer, and angiosperm taxa only, namely of *Onychiopsis, Ptiophyllum*, and *Graminophyllum* genera. The Omsukchan and central Mongolian floras lack *Athrotaxopsis* forms dominant in the Dzun-Bayan flora and leaf imprints of arboreal dicotyledons. Angiosperms are mainly represented in these floras by aquatic-riparian monocotyledons, leaving aside questionable seeds of *Gurvanella* and *Erenia*. A significant difference between the floras under comparison may be a consequence of connections between the northeastern central Mongolia and Siberian phytochore in the Aptian–Albian time, whereas the southern Gobi was in the Indo-European region populated by subtropical flora, where the influence of the Central Asian semiarid zone was perceptible (Vakhrameev, 1990). Were the floras incorporating the arboreal angiosperms, remains of the latter would have been encountered in plant assemblages discovered in more than five localities. The Dzun-Bayan flora is resembling the Aptian Manlai flora found in the east of the southern Gobi (Krassilov, 1980). The latter also lacks leaves of arboreal dicotyledons, being represented by leaves, stems, and inflorescences of monocotyledons and by abundant fossil roots of herbaceous plants. This was an evidence for Krassilov to suggest that shores around the Manlai Lake were woodless in the Aptian. Shuvalov (1982) was of another viewpoint. Describing the Aptian–Albian land-



Localities of Aptian–Albian and Late Cretaceous floras in the southern Gobi: (1) studied region; (2) orogenic massifs composed of pre-Cretaceous rocks; (3) outcrops of the Albian and Upper Cretaceous sequences; (4) floral localities.

scapes of the southern Gobi, he suggested that forest vegetation was confined in most humid mountainous and northern regions to riverbanks and lake coasts, while plains were occupied by sparse growths of trees and arid savannas. In his opinion, climate in the greater part of Mongolia was relatively humid at the beginning of the Aptian–Albian time, and thick forests grew not on watersheds only, but also closely approached rivers and lakes. In the terminal Albian, climate of the Mongolian Gobi sharply changed, became semiarid to arid. The arid climatic zone existed there up to the end of the Cretaceous.

Bain-Shire Formation (Cenomanian–Turonian). The formation was distinguished by Berkey and Morris (1927) in the Oshi Group of central Mongolia, in the Oshi-Nuru Range region. Subsequently it was recognized to the south of the Mondal-Obo Village in the eastern Gobi. The most complete sections of the Bain-Shire Formation are known in the Khara-Khutul Range and at the Bain-Shire and Khongil-Tsav sites. rocks of the formation occur as well in the Khermin-Tsav site and Shiregin-Gashun depression of the Trans-Altai Gobi. The Bain-Shire Formation unconformably overlies as a rule the older Mesozoic and Paleozoic sediments. Its lower part is composed of gray to variegated sandstones and gravelites intercalated with clay and siltstone beds, while the upper one is represented by red beds. The facies composition is variable in different sections. Alluvial and lacustrine-alluvial cross-bedded sediments are widespread in the formation lower part. Lacustrine facies contain remains of dinosaurs, turtles, mollusks, ostracodes, charophytes, and fruits of Cenomanian–Turonian angiosperms. In the upper part, red and gray beds, fine-grained clays and siltstones bear abundant remains of invertebrate and vertebrate fauna (Martinson *et al.*, 1969; Shuvalov, 1975). In the Trans-Altai Gobi, the Bain-Shire Formation underlies in places the Barun-Goiot Formation. At Ongon-Ulan-Ula site, Sochava (1975) initially referred these sediments to the Sain-Shanda Formation, although later on they were dated back to the Cenomanian–Turonian based on ostracode fauna and attributed to the Bain-Shire Formation (Stankevich, 1979). Flora-bearing beds of the formation yield ostracodes *Cipridea* aff. *profusa* Lub., *Eucypris hermintsavica* St., *Lycopterocypris bagataraschinensis*, and *Mongolianella* sp. The most typical among them is *L. bagataraschinensis* encountered mainly at the Bain-Shire site. Exposures of the formation are also known in the lowered part of the Shiregin-Gashun depression northwest of the Ulan-Tsab-Ula Upland, where skeletons of ankylosaur *Syrmosaurus disparoserratus* Maleyev (Maleev, 1952) and crocodile *Shamosucyus (=Paralligator) grandilifrous* Konzhukova (Konzhukova, 1954) were found. Martinson (1982) encountered finely preserved *Araucaria* cones identified *Araucaria gobiensis* Makul., sp. nov. in yellowish gray to reddish brown loose sandstones intercalated with clay beds.

Near southern foothills of the Khara-Khutul-Ula Range, the Bain-Shire Formation is represented near the base by light gray fine-grained sandstones reddish brown clays. In these sediments, Martinson found fruits of *Bothrocaryum gobiense* Krassilov and *Nyssoidea mongolica* Krassilov of the Cenomanian–Turonian age (Krassilov and Martinson, 1982).

Kyansep-Romashkina (1982) recognized the Baishin-Tsav and Unegetin charophyte assemblages in the Bain-Shire Formation of southern Mongolia. The former includes *Atopochara* aff. *trivolvis* Peck, *A. restricta* Grambast, *A.* sp., *Mesochara shuvalovii* Kyansep-Rom., *M. sainshandica* Kyansep-Rom., and *Harrisichara cretacea* Karczew. et Ziemb.-Tworz. Species *Atopochara trivolvis* is widespread in the Lower Cretaceous sediments of North America, Western Europe, Central Asia, northern Africa, and Mongolia. *Atopochara restricta* is known from the Aptian–Albian of Spain. In Mongolia, it was encountered in the Bain-Shire Formation on Mt. Khara-Khutul and in the Baishin-Tsav scarps. Species *Mesochara shuvalovii* was found in the Bain-Shire Formation of the Shiregin-Gashun depression (the Ulan-Tsav-Ula section) and in the eastern Gobi on Mt. Khara-Khutul and Mt. Baishin-Tsav. *Harrisichara cretacea* was first encountered in the Nemegt formation of the southern Gobi (Karczewska and Ziembinska-Tworzidlo, 1970) and subsequently in the Bain-Shire Formation of the Bain-Shire and Baishin-Tsav sections. The reported data show that the Baishin-Tsav charophyte assemblage of the Bain-Shire Formation includes species that are widespread in the terminal Lower Cretaceous. Some of them existed as well during the Late Cretaceous in the southern Mongolia. However, *Harrisichara cretacea* characteristic of the late Senonian time in Mongolia suggests that respective interval of the section can be actually older.

The second charophyte assemblage of the Bain-Shire Formation includes *Mongolichara attenuata* Kyansep-Rom. and *M. paucicostata* Kyansep-Rom., the endemics of the Nemegt time in Mongolia. This part of the section is probably younger, belonging to the late Turonian.

Mollusks from the Bain-Shire Formation exposed including on northwestern slopes of Mt. Ongon-Ulan-Ula, the Trans-Altai Gobi, are divided into three assemblages suggesting the Cenomanian–Santonian range of their host sediments (Martinson, 1982). Based on the found dinosaur remains, Barsbold (1983) assigned the Bain-Shire Formation to the Turonian and considered segnosaurs, dromeosaurs, ornithomimids, garudimimids, and tyrannosaurs as characteristic of theropod community of southern Mongolia at that time. Segnosaurs most typical of that community are known in the eastern Gobi from this formation only. The theropod fauna of the Bain-Shire Formation is largely peculiar and has not analogues elsewhere in and outside of Mongolia.

The Ongon-Ulan-Ula flora was found first by D. Badamgarav in the Engeni-Khobur depression of the Trans-Altai Gobi. In 1983, I collected plant remains from the blue cross-bedded clays and siltstones bearing ostracodes and elytra of leaf beetles and exposed near the northern foot of the same mountain. Based on ostracodes (Martinson, 1982), the above sediments belong to the Bain-Shire Formation. The apparent thickness of the formation is about 47 m at this site.

The Ongon-Ulan-Ula flora known from the lower lacustrine facies of the Bain-Shire Formation was studied in about 60 samples. It is mainly represented by aquatic and aquatic-riparian plants *Nelumbo* sp., *Phragmites* ex gr. *alaskana* Heer, *Monocotyledonea* gen. sp., and *Phyllites* sp. Dominant in the samples are well-preserved impressions of fruits, leaves, stems, and earheads of a new genus likely belonging to alismatids.

Barun-Goiot Formation (Santonian–Campanian). Red beds of this formation were first described under names the Sairim and Dzhadokhta formations by Berkey and Morris (1927) nearby the Sairin-Us-Khuduk Well and at the Bain-Dzak site. Later on, they were distinguished in other regions of southern Mongolia, primarily in the Gobi and Gobi-Alai areas, where these beds are even more widespread than those of the Bain-Shire Formation. Some researchers (Shuvalov, 1975, 1982; Martinson, 1982) attribute the beds to the Barun-Goiot Formation in contrast to others (Barsbold, 1983) who include them into the Dzhadokhta Horizon incorporating the Dzhadokhta and Barun-Goiot formations. In this work, I adhere the viewpoint of Shuvalov and Martinson. As noted above, the Barun-Goiot Formation is mainly composed of red beds of well-sorted sandstone with yellowish or brownish tints, which are intercalated with clayey and gravelstone interlayers. In places, sandstones are grayish or yellowish gray in some sections. In marginal parts of the depressions, e.g., at the Khermin-Tsav and Gurlin-Tsav sites of the Trans-Altai Gobi, they enclose conglomerate beds with poorly rounded pebbles.

The Barun-Goiot Formation is of persistent lithologic composition over the vast region that is indicative of lacustrine genesis of its sediments, although some horizons are of proluvial and eolian origin. The Barun-Goiot Formation is commonly 50 to 60 m thick, being nowhere thicker than 100–120 m. Nobody of researchers questioned the Late Cretaceous age of the formation that is evidenced by found vertebrate remains, mollusks, and charophytes, although opinions concerning its more exact stratigraphic range are diverging. Efremov (1954) referred the Bain-Dzak sandstones to the lowermost Upper Cretaceous. Berkey and Morris (1927) originally considered the Bain-Dzak and Sairin-Us-Khuduk sediments as the basal Upper Cretaceous as well. In his later work, Morris (1936) admitted, referring to contradictions between American paleontologists who studied different faunal groups from the Bain-Dzak locality, that the Dzhadokhta Formation may correspond to higher levels of the Upper Cretaceous. At present, the Santonian–Campanian age of the

Barun-Goiot Formation is substantiated based on numerous bone remains and eggs of dinosaurs, turtles, and lizards, as well as on mollusks and charophytes (Martinson, 1982; Barsbold, 1983; Kyansep-Romashkina, 1982; Alifanov, 1993a, b). In opinion of Barsbold, the Dzhadokhta Horizon contains two dinosaur assemblages different in taxonomic composition, the Dzhadokhta proper and Barun-Goiot faunas. The Dzhadokhta fauna is best represented in the Bain-Dzak, Tugrikin-Shire, and Dzamyn-Khond localities of southern Mongolia. The Barun-Goiot fauna is known from richest burials of dinosaur bones at the Khermin-Tsav and Khulsan sites in the Trans-Altai Gobi. According to Alifanov (1993a), the Dzhadokhta fauna includes bones of dinosaurs *Protoceratops, Oviraptor*, and lizard families Diploglossidae, Isodontosauridat, Macrocephalosauridae, Mongolochamipidae, Priscagamidae, Pleurodontagamidae, and Saniwidae. Taxa identified in the Barun-Goiot assemblage are dinosaurs *Bagaceratops* and *Conchoraptor* and lizards Cherminsauridae, Macrocephalosauridae, Mongolochamipidae, Parasaniwidae, Pleurodontagamidae, Priscagamidae, Saniwidae, Slavoidae, and others.

In the Bamba-Khuduk, Ingeni-Tsav, Nogon-Tsav, and Altan-Ula localities of the Barun-Goiot Formation in the southern Gobi, Martinson (1982) identified mollusks *Pseudohyria barungoiotica* Martins., *P. ingenihoburensis* Martins., *P. multicostata* Martins., *P. elongata* Martins., *Buginella* cf. *laevivalvata* (Barsbold), *B.* sp., and *Plicatotrigonioides* sp. In his opinion, this assemblage consisting of new species cannot be compared with those from other regions of Asia. Thus, the Campanian age of the assemblage is estimated based on remains of Ankylosauridae and Ceratopsidae. Charophytes encountered in the Barun-Goiot Formation at the Bamba-Khuduk, Altan-Ula, Khermin-Tsav, and Ongon-Ulan-Ula sites of the Trans-Altai Gobi are also of the Campanian age. Identified at these sites are *Mongolichara gobica* Karcz. et Kyansep-Rom., *Lamprothamnium bambuhudukae* Kyansep-Rom., *Mesochara oviformis* Kyansep-Rom., *M. sainshandica* Kyansep-Rom., *Maedlerisphaera pseudoulmensis* Karcz. et Ziemb.-Tw., *Grambastichara* sp., *Saportanella barsboldii* sp. nov., *Raskyella rosuliforma* sp. nov., and *Atopochara barungoiotica* sp. nov. Consequently, there was likely a vast lake in the Trans-Altai Gobi during the Barun-Goiot time, where quiet shoals were inhabited by eight species of charophytes.

In 1986, I discovered burials of terrestrial and aquatic floras locality in the lower part of the Barun-Goiot Formation at Mt. Altan-Ula 4 site, where they are confined to gray clay and siltstone lenses. The identified plant taxa are *Osmunda cretaceae* Samyl., *Nilssonia serotina* Heer, *Ginkgo* sp., *Phragmites* ex gr. *alaskana* Heer, *Podozamites* ex gr. *minor* Samyl., *Libocedrus catenullata* Bell, *Thuja cretaceae* (Heer) Newb., *Pityophyllum nordenskioldia* (Heer) Brown, *Glyptostrobus nordenskioldia* (Heer) Brown, *Platanus* sp., *Nyssa punctata* Heer, *Myrica* sp., *Carpinus* sp., *Nelumbites minimus* Vachr., *Phyllites* sp., and *Carpolithes* sp.

The flora is dominated by Ginkgoales and conifer taxa, many of which are first found in Mongolia. Arboreal angiosperms are less abundant and represented mainly by fragments of small leaves. Aquatic plants of the genus *Nelumbites* are few. Leaves of aquatic-riparian *Phragmites* ex gr. *alaskana* with a distinct parallel venation are numerous. The assemblage lacks horsetails and includes few ferns. Its peculiar character is presence of a new *Ginkgo* species that is most likely untypical of Maastrichtian floral assemblages from southern Gobi.

Along with floral remains, numerous elytra of snout (Curculionidae) and water beetles (Hydrophilidae) of a Cenozoic affinity were found for the first time in Central Asia. Elytra of Mesozoic *Hydrobiites*, two species of leaf beetles *Plateumaris* (Donaciinae), and one species of ground beetle (Carabidae), which are present in the Bain-Shire Formation as well, though in a lesser amount, were also detected among insect remains from the Ongon-Ulan-Ula site (identifications by A.G. Ponomarenko).

The floral assemblage and coexisting aquatic beetles and conchostracans are useful for reconstruction of Campanian biocoenoses in the Trans-Altai Gobi. Coastal zone around a vast lake that presumably existed at that time close to Mt. Altan-Ula was covered by forests of coniferous and accessory ginkgo, sycamores, hornbeams, wax tree, snag tree, and others. Various grasses populated riparian belt. Snout leaf and water beetles swam on the water surface among leaves of water lilies.

The Nemegt Formation (Maastrichtian) terminates the Upper Cretaceous sections in the Trans-Altai Gobi. Sediments of the formation cover large areas in the Khermin-Tsav, Nogon-Tsav, Bugin-Tsav, Khaichin-Ula, Bamu-Khuduk, Naran-Bulak, Ulan-Bulak, Tsagan-Khushu, Nemegt-Ula, Altan-Ula, Gurlin-Tsav, Ingeni-Khobur, Bagmond-Khuduk, and Baing-Bologai badlands (Shuvalov, 1982; Martinson, 1982; Jerzykiewicz and Russell, 1991). In the Shiregin-Gashun depression outcrops of the Nemegt Formation are known at the Khuren-Tsav site, near the Khatsar-Us-Khuduk Well, and in the Udan-Saira region. In these localities, the Nemegt Formation conformably overlies the Barun-Goiot red beds replacing them gradually upward in the sections.

The Nemegt Formation is universally represented by gray and greenish to yellowish gray rhythmically interbedded clays and sandstones with thin (up to 0.5–0.7 m) gravelstone and conglomerate interlayers. Some sandstone and clay layers are reddish brown to brownish gray, imparting a general variegated outlook to the Nemegt sediments in the region.

Sections of the formation are rather homogeneous in the facies aspect, composed predominantly of lacustrine and rarer lacustrine-alluvial sediments, as it is

inferred from encountered assemblages of fossil mollusks, ostracodes, conchostracans, turtles, and charophytes (Martinson, 1975, 1982; Shuvalov and Chkhikvadze, 1975; Kyansep-Romashkina, 1982). Based on these groups of fossils, Shuvalov (1982) argued against opinion of Gradzinski (1970) and Sochava (1975) who assumed predominantly alluvial genesis of the Nemegt Formation. The alluvial and intermittent-flow facies are rare. The Nemegt sediments host richest localities of the Cretaceous dinosaurs, turtles, lizards, and mammals in Central Asia. They also yield associated mollusks, ostracodes, charophytes, terrestrial and aquatic flora, and insect remains. According to Martinson (1982), assemblage of mollusks from the Nemegt Formation of the Trans-Altai Gobi includes up to 19 species characterizing age of sediments and their facies affinity. For instance, gastropods generally occur in fine-grained sandstones and clays, whereas large bivalves are associated with coarse-grained sandstones and pseudogravelstones. Their internal molds were also found in clayey beds of the Altan-Ula and Nemegt-Ula sites. Gastropods *Mesolanistes* described from the Maastrichtian of Utah (Yen, 1964), North America, and of northern China (Suzuki, 1942), are of major importance for age determination of the Nemegt Formation. In the Nogon-Tsav area, Barsbold (1972) distinguished the Maastrichtian Nogon-Tsav Formation that, in his opinion, terminates the Upper Cretaceous section of the Trans-Altai Gobi. His conclusion was based on a misleading assumption that bivalves *Buginella* and *Pseudohyria* are missing from an upper part of the Nemegt Formation at the Nogon-Tsav site. In opinion of Martinson, the Nogon-Tsav Formation is distinguished incorrectly, since the above mollusks are of the same age but characteristic of different facies. *Buginella* forms are more typical of the lower and middle parts of the Nemegt section, being commonly replaced by *Pseudohyria* in the upper part. A good example is known from upper parts of the Bugin-Tsav and Naran-Bulak sections, where only *Pseudohyria buginzabica* Martins. and *P. autochthona* Barsb. occur.

The Nemegt Formation yields an ostracode assemblage of over 33 species that is most diverse in the southern Gobi (Stankevich, 1982). Among them, 14 taxa are characteristic of the formation only. *Cypridea flexdarsalis* Lub. and *Mongolianella khamarinensis* Gal. known from the Lower Cretaceous of Mongolia were found at the Upper Cretaceous level in the Nemegt Formation only. Among 33 taxa, 16 species are new for the ostracode fauna of the southern Gobi, 15 are associated with the Barun-Goiot Formation of the region, and only two species transit into the Early Paleogene.

The Nemegt Formation also yields vertebrates remains. They represent turtles *Basilemys, Mongolemys, Trionyx*, and *Yumenemys*, dinosaurs *Nemegtosaurus, Saurolophus, Tarbosaurus, Therizinosaurus, Shamosuchus, Adasurus, Velociraptor, Oviraptor, Awimimus*, and others, lizards Mongolochamopidae, Parasaniwidae, Tupinambidae, and Varanidae, and mammals *Buginbaator.*

Charophytes from the Nemegt Formation are abundant, diverse, and studied in detail by Karczewska and Ziembinska-Tworzidlo (1970) and by Kyansep-Romashkina (1975, 1982). Especially abundant charophyte remains are known from the aforementioned classic localities of vertebrate fauna in the Trans-Altai Gobi.

I collected numerous impressions of leaves, stems, fruits, and megaspores of riparian-aquatic and aquatic, mostly endemic plants from the lower Maastrichtian part of the Nemegt Formation that is composed of lacustrine sediments at the Tsagan-Khushu and Ulan-Bulak sites. Impressions of Gastromycetes reproductive organs with opened exoperidium and intact capitulum, which likely belong to the extinct genus *Geastroides*, were also found here (Krassilov and Makulbekov, 2003). Megasporophylls of the extinct genus *Isoetites*, pondweed shoots, and duckweed seeds were identified in the collection as well (Krassilov and Makulbekov, 1995). The preservation state of these remains was suitable for a careful investigation of morphology and cuticle structure of the pericarp and seeds.

In 1984, a new locality of the Late Cretaceous flora was found between the Dushi-Ula and Ongon-Ulan-Ula mounts of the Trans-Altai Gobi in the middle beds of the Nemegt Formation, which are composed of foliated clayey lacustrine sandstones in the Nogon-Tsav section. Plant impressions of *Nelumbo* sp., *Quereuxia rotundifolia* Golovn., *Zingiberopsis* sp., *Phragmites* ex gr. *alaskana* Heer, and *Arundo* ex gr. *goeppertii* (Muenst.) Heer referred to the middle Maastrichtian were encountered here in association with ostracodes, mollusks, and ankylosaur remains.

In the same part of the Nemegt Formation exposed at the Bugin-Tsav site, Martinson found seeds of *Nyssoidea mongolica* Krassilov (Krassilov and Martinson, 1982). Afterward I sampled the same sediments once more, found again the seeds and encountered numerous impressions of monocotyledon plants. As noted above, they were also found in the Bain-Shire Formation of the Khara-Khutul-Ula Range of the southeastern Gobi. In opinion of Krassilov, *Nyssoidea* dominated the shrub vegetation in areas under consideration.

In the upper Maastrichtian part of the Nemegt Formation at the Ulan-Bulak, Tsagan-Khushu, Bugin-Tsav, Altan-Ula, and Khermin-Tsav outcrops, the impressions of small sycamore leaves, sterile shoots of bog cypress and glyptostrobus, and numerous leaves and shoots of monocotyledon *Arundo* and *Phragmites* were identified. In places, the upper Maastrichtian assemblage includes scarce small leaves of *Trochodendroides*, a taxon dominant in the Paleocene floras of the region.

Early and Late Cretaceous flora in the formations of southern Mongolia

Taxa \ Formations / Age	Barun-Bayan K_1 al K_1 a	Bain-Shire K_2 t K_2 c	Barun-Goiot K_2 cp K_2 s	Nemegt K_2 m
Geastroides lobata Krassil., sp. nov.	–	–	–	+
Moniliteca minuta Krassil. et Makyl., sp. nov.	–	–	–	+
Isoetites sp.	–	–	–	+
Equisetites sp.	–	–	+	–
Osmundo cretaceae Samyl.	–	–	+	+
Onychyopsis psilotoides (Stokes et Webb.) Ward	+	–	–	–
Nilssonia seratina Heer	–	–	+	–
Ginkgo sp.	–	–	+	–
Ginkgo ex gr. *adiantoides* (Ung.) Heer	+	–	+	–
Podozamites ex gr. *minor* Samyl.	–	–	–	+
Araucaria gobiensis Makul., sp. nov.	–	–	+	–
Araucarites sp.	+	–	+	–
Pityophyllum ex gr. *nordenskioldii* (Heer) Nath.	+	–	+	–
Sequoia microlepis Sveshn.	+	–	+	–
Taxodium dubium (Sternb.) Heer	–	–	+	+
Glyptostrobus ex gr. *nordenskioldii* (Heer) Brown.	–	–	+	+
Libocedrus catenulata Bell.	–	–	+	+
Thuja cretaceae (Heer) Newb.	–	–	+	+
Athrotaxopsis grandis Font.	+	–	–	–
Nelumbo sp.	–	–	+	+
Nelumbo minimus Vachr.	–	+	–	+
Trochodendroides ex gr. *arctica* (Heer) Berry	–	–	–	+
"*Platanus*" ex gr. *raynoldsii* Newb.	–	–	–	+
Carpinus sp.	–	–	+	–
Nyssa punctata Heer	–	–	+	+
Nyssoidea mongolica Krassil.	–	–	+	–
Bothrocaryum gobiensis Krassil.	–	–	+	–
Quereuxia rotundifolia Golovn.	–	–	–	+
Potamogeton sp.	–	–	–	+
Lemna sp.	–	–	–	+
Phragmites ex gr. *alaskana* Heer	+	+	+	+
Arundo ex gr. *goeppertii* (Muenst) Heer	+	+	+	+
Zingiberopsis sp.	–	–	–	+
Monocotyledonea gen. sp.	+	+	+	+
Phyllites sp.	+	+	+	+

EARLY AND LATE CRETACEOUS FLORAL ASSEMBLAGES OF SOUTHERN MONGOLIA

Four plant assemblages are distinguished in the Aptian–Albian and Late Cretaceous floras of southern Mongolia. In the Aptian–Albian Barun-Bayan assemblage rare angiosperm plants are represented by small leaves with venation of uncertain type, and conifers are dominants. The Cenomanian–Turonian Bain-Shire assemblage is dominated in contrast by riparian-aquatic angiosperms, while conifers are scarce in it. In the San-

tonian–Campanian Barun-Goiot assemblage, terrestrial plants, primarily conifers and angiosperms, are of a higher diversity. "Platanaceae," hornbeams, and snag trees appeared among them. In distinction from previous taphocoenoses, the Maastrichtian Nemegt assemblage includes terrestrial fungi, lycopods, and *Trochodendroides*. Many new taxa of aquatic plants, e.g., *Nelumbo, Potamogeton*, and *Lemna*, occur in this assemblage. Abundance of conifers and broad-leaved arboreal plants decreased. These changes in vegetation cover of the southern Gobi reflect growing aridity of climate in Central Asia during the Late Cretaceous and increasing proportion of riparian and aquatic taxa in coenoses.

Barun-Bayan assemblage. Fossil ferns of this assemblage are represented by few pinnules of sterile leaves of *Onychiopsis psilotoides* (Stokes et Webb.) Ward, a species widespread in the Early Cretaceous floras of the European-Sinian (Indo-European) and, to a lesser extent, of the Siberian-Canadian phytochores of Eurasia and North America, mainly in the second half of the Early Cretaceous. Genera *Pityophyllum, Athrotaxopsis, Araucarites*, and *Sequoia* prevail among conifers. Rather common needles with a single midrib, about 3–4 mm wide and over 5 cm long, are referred to the first genus. Similar needles attributed formerly to *Pityophyllum* that is close to Pinaceae are widespread in the Cretaceous sediments of Eurasia and North America. Conifer remains are dominated by *Athrotaxopsis* leafy shoots richly branching in one plane. Taxonomic position of the genus was unclear until recently. Judging from fossil cones, Krassilov (1967) concluded that this genus was close to *Sequoia* and *Sequoiadendron*, although cones are smaller in distinction. In his opinion, *Athrotaxopsis* should be considered as a separate genus though similar to *Sequoiadendron*. Other researchers who described *Athrotaxopsis* commonly indicated similarity of its vegetative shoots with those of *Cyparassidium*. Terminal shoots of both genera are actually very similar and, when found in fragments, can be easily misinterpreted. However, branching shoots of *Athrotaxopsis* differ greatly from those of *Cyparassidium*, as they are almost bald in axes of leading branches and their terminal sprigs are branching more thickly. Female cones of two genera considerably differ as well. According to branching of shoots and leafiness of their basal axes, genera under discussion are also similar to recent genus *Athrotaxis* that is widespread nowadays in the Southern Hemisphere, e.g., in mountains of western Tasmania between altitudes of about 900 to 1300 m. It difficult to establish the precise taxonomic affinity of the genus *Athrotaxopsis* from the Dzun-Bayan assemblage, but it definitely belongs to Taxodiaceae.

Ginkgo is represented by several fragmented leaf impressions unsuitable for examination of venation type. These impressions are attributed therefore to the combined taxon *G.* ex gr. *adiantoides* (Ung.) Heer that is widespread in the Early and Late Cretaceous floras of Central Asia.

Angiosperm remains, primarily dominant leaf impressions of a new dicotyledon genus, are second in abundance. Leaves are small in size, with venation of uncertain type. Analogous leaves are rather common in the Aptian–Albian floras of Eurasia and North America and are divided in general into morphotypes of Leguminosae and Lauraceae (Doyle and Hickey, 1972; Hickey and Doyle, 1977; Samylina, 1976; Knobloch, 1978; Krassilov, 1979, 1989b). Leaves from the southern Gobi are referred to the former group. Few leaves of uncertain shape are attributed to *Dicotylophyllum* sp.

Bain-Shire assemblage. This assemblage includes terrestrial and aquatic plant taxa encountered in different localities of the Bain-Shire Formation in the southern Gobi. The former are represented by arboreal genus *Araucaria* and by shrubs taxa *Bothrocaryum* and *Nyssoidea*, which likely occupied open and elevated areas in the Trans-Altai Gobi. At present, the genus *Araucaria* occurs in South America, Australia, and New Guinea, i.e., in the discrete distribution areas thus examplifying situation, when species of one genus grow in different continents.

This undoubtedly implies that continents likely drifted apart in the Mesozoic, since in the Tertiary South America was already separated from Australia. Shoots, leaves, cones, seeds, and pollen of *Araucaria* were also found in the Northern Hemisphere that possibly hosted a radiation center of the genus known here from the Jurassic. In Mongolia, *Araucaria* remains are recorded beginning from the Aptian, being the components of Bon-Tsagan, Shin-Khuduk, Kholbotu, and Erdeni-Ula floras (Krassilov, 1982).

Cornaceae and Nyssaceae are identified based on their carpolites. *Bothrocaryum* (*Cornus*) *alternifolium* (L.) Pojark. and *B. controversum* (Hemsl.) Pojark. are known from the Oligocene and younger sediments. *Bothrocaryum* is presently united with *Cornus*, endocarps with four nidi are also characteristic of the latter. Chandler (1961) described fruits with a quadrilocular endocarp as *Cornus quadrilocularis*. Recent representatives of the genus occur predominantly in subtropical and temperate belts of the Northern Hemisphere. Commonly these are deciduous trees and bushes, although some species are known in low undershrub growing along riverbanks and lake coasts.

Fossil Nyssaceae occur beginning from the Lower Cretaceous. Leaves and endocarps, rarely fruits with pericarps are commonly preserved. As is argued in some works (Kirchheimer, 1938, 1957; Eyde and Barghoorn, 1963), some Cretaceous *Nyssoidea* identified in leaf impressions do not belong to the genus. Authentic leaves of *Nyssoidea* are known from the Cretaceous Tsagayan flora of the Amur region (Krassilov, 1976). Fruits of Nyssaceae from the Eocene flora of England were described as *Protonyssa, Palaeonyssa*, and *Nyssoidea*, which differ in number of nidi in endocarps. Endocarps the latter genus are unilocular. *Nyssoidea* differs from *Nyssa* in the presence of short longitudinal

ribs in endocarp. Recent Nyssaceae are predominantly deciduous trees and bushes. *Nyssa* is characterized in discrete distribution areas remained after a vast region populated by the genus in the Cretaceous–Tertiary time. About five species grow now in the Atlantic part of North America and two species occur in southern and southeastern Asia. *N. aquatica* together with bald cypress are components of swamp forests in lowlands of the southeastern United States, e.g., in the Mississippi River basin and northern Florida. *N. sylvatica* is most widespread, being typical of mesophilic and mixed forests from North America to southern Canada. *N. sinensis* grows in mesophilic mountainous forests of southern China, and distribution area of *N. javanica* reaches the equator. Throughout its distribution area from eastern Himalayas to Borneo, the last taxon grows in virgin mountainous tropical forests.

Aquatic plants are also of importance in the assemblage. Remarkable among their remains are several leaf impressions with radiating midribs bifurcating once or twice close to the leaf edge. This morphological peculiarity discriminated genus *Nelumbo* from the formal genus *Nelumbites*, in leaves of which midribs repeatedly bifurcate beginning almost from the middle of a leaf blade. *Nelumbites* was originally considered as ancestor of *Nelumbo* and was referred to either Nymphaeaceae or Nelumbonaceae. Seward (1926) referred the genus *Nelumbites* to Menispermaceae (*Fundamentals of Paleontology*, 1963). The *Nelumbo* leaves from the Bain-Shire assemblage are poorly preserved, being inappropriate for identification at the species level.

The assemblage also includes abundant fruits, leaves, and stems of a new genus and species of aquatic plants likely belonging to Potamogetonaceae. Vegetative organs of new forms are very similar to those of the family representatives, whereas generative ones are quite different, enabling recognition of the new genus and species, which will be systematically described in nearest future. In addition to mentioned taxa, the assemblage includes leaves and stems of monocotyledons identified as *Phragmites* ex gr. *alaskana* Heer and Monocotyledoneae gen. sp. All the data suggest that landscapes of the Bain-Shire time in the Trans-Altai Gobi included freshwater lakes with lotuses and pondweeds, and with coasts overgrown with reeds, various herbs, bushes, and trees.

Barun-Goiot assemblage. The assemblage contains an impression of isolated *Osmunda* pinnules with morphological features characteristic of ferns *Osmunda cretaceae* Samyl. identified in the Late Cretaceous floras of North Asia. Recent *Osmunda* species occur in both hemispheres from the Great Lakes in the west and from Kamchatka in the north to southeastern Asia in the east.

Cycadaceae are represented in the assemblage by a leaf fragment of *Nilssonia serotina* Heer. This polymorphic species is widespread in Upper Cretaceous sediments in circum-Pacific regions of North Asia and North America. Now it is also found in Central Asia. Morphologically close species is *N. alaskana* Hollick (Hollick, 1930) from Alaska and other localities. The Barun-Goiot assemblage is dominated by gymnosperms, the well-preserved leaf impressions of *Ginkgo* sp. nov. included. In southern Mongolia, *Ginkgo* representatives were known formerly as *Ginkgoites* cf. *dissektus* Krassil. from the Barremian–Aptian Manlai flora (Krassilov, 1980) and as *G. mongolensis* Krassil. from the Shin-Khuduk assemblage (Krassilov, 1982). Authentic leaf impressions of *Ginkgo* from the Santonian–Campanian flora of Mt. Altan-Ula 4 indicates a wide stratigraphic range of the genus in the southern Gobi. According to Samylina (1978), paleobotanic records show that morphologic evolution of *Ginkgo* leaves progressed toward a lesser dissection of leaf blades. Triassic and most of Jurassic *Ginkgo* had leaves dissected into distinct 4 to 12 or more lobes. *Ginkgo* species, which appeared in the mid-Jurassic time had almost entire leaves slightly incised along edges. In the Early Cretaceous, *Ginkgo* with entire leaves became rather widespread, while species with dissected leaves decreased in abundance. In the Late Cretaceous and Tertiary, only species with entire or slightly dissected leaves remained. The oldest *Ginkgo* remains were found in the Triassic. Subsequently they became widespread Mesozoic floras of the Northern Hemisphere, especially in the Siberian phytochore. Recent *Ginkgo* grow only in low reaches of the Yangtze River in China.

Conifers *Podozamites, Libocedrus, Thuja, Pityophyllum*, and *Glyptostrobus* are common components of the assemblage. Leafy shoots of *Libocedrus* and *Thuja* are most abundant in this group. Dicotyledons are represented by fragments of small leaves of *Platanus, Nyssa, Myrica*, and *Nelumbo*. There are many leaves and stems of monocotyledon taxa identified as *Phragmites* and Monocotyledonea gen. sp.

Nemegt assemblage. Fruit bodies of Gasteromycetes similar to recent genus *Geastrum* Pers. but differing from it in the mode of exoperidium opening were found in the Upper Cretaceous sediments of Tsagan-Khushu site for the first time in Central Asia. Being formerly unknown below the Miocene, these fruit bodies are identified as a new genus *Geastroides* Krassilov gen. nov. elucidating evolution of Gasteromycetes and ecology of Late Cretaceous biocoenoses in Central Asia. According to Krasilov and Makulbekov (2003), these fungi likely inhabited open areas along water basins like recent *Geastrum* forms.

Lycopods are represented by a megasporophyll of the extinct genus *Isoetites* distinguished by Muenster in 1842 and later described by Seward (1910) from Early Cretaceous floras of Portugal. Fossil vegetative and reproductive organs of the genus are known beginning from the Lower Cretaceous. *I. horridus* (Dawson) Brown from the Paleogene of North America is the type species (Borsuk, 1963). Recent descendant *Isoetes* is riparian aquatic plant that grows partially submersed,

being of variable height from 2 to 90 cm. *Isoetes* forms are widespread throughout the world, from tropical realm to Greenland and from coastal lowlands to high mountains. Aquatic species of the genus commonly inhabit oligotrophic lakes with weekly acid or truly fresh, very transparent water, frequently forming thickets at the bottom. Riparian representatives most commonly grow from bottoms of shallow temporary basins, shedding leaves by exsiccation and easily surviving arid periods.

Proportion of conifers in the Nemegt assemblage is much lower than in the previous one. Present among them are leafy shoots and leaves of *Taxodium dubium* (Sternb.) Heer and *Glyptostrobus* ex gr. *europaeus* (Brongn) Heer, which are widespread in the Late Cretaceous and Paleogene sediments of Eurasia.

Angiosperms are more abundant and diverse in contrast. This group is dominated by aquatic (*Nelumbo, Quereuxia, Zingiberopsis, Lemna*) and riparian (*Phragmites, Arundo*) taxa. Fragmentary leaves of xerophilous *Trochodendroides arctica* and *"Platanus" raynoldsii* are few. This likely means that *Platanus* forests completed their development in the southern Gobi, when transition from arid to warm temperate climate in the terminal Maastrichtian stimulated predominance of *Trochodendroides* forms in arboreal vegetation of the region. Fruits of *Nyssoidea mongolica* encountered in the Bain-Shire assemblage imply that this taxon was an endemic of forest vegetation in the southern Gobi.

Aquatic plants of the Nemegt assemblage are mostly represented by species, which are new for Late Cretaceous floras known in the study region. I planed to describe in the next paper a new *Nelumbo* species with peculiar collective fruits that have no fossil or recent analogues so far known in botany. In addition, the Nogon-Tsav flora includes leaves of lotus, *Quereuxia*, and *Zingiberopsis*. In the Tsagan-Khushu locality, numerous fruits of *Lemna* sp. (Krassilov and Makulbekov, 1995) representing a new Lemnaceae species were found in the lowermost part of the Nemegt Formation. Lemnaceae are aquatic free-floating, mostly perennial herbaceous plants that occur on all continents from tropical regions to the temperate realm. It is the smallest flowering plant less than 1 cm in size. Their fruits ascidiform or saccate in shape incorporate one to six seeds.

Below is the list in taxonomic succession of all plant taxa I identified in the Middle and Late Cretaceous floras of the southern Gobi.[1]

Gasteromycetes: **Geastroides* Krassil., gen. nov., **G. lobata* Krassil., gen. sp. nov. Isoetales: *Isoetites* sp., **Monilitheca minuta* Krassil. et Makul., gen. sp. nov. Equisetales: *Equisetites* sp. Filicales: *Osmunda cretaceae* Samyl., *Onychiopsis psilotoides* (Stokes et Webb) Ward. Cycadales: *Nilssonia seratina* Heer. Ginkgoales: *Ginkgo* ex gr. *adiantoides* (Ung.) Heer, *Ginkgo* sp. Coniferales: *Podozamites* ex gr. *minor* Samyl., **Araucaria gobiensis* Makul., sp. nov., *Araucarites* sp., *Pityophyllum* ex gr. *nordenskioldii* (Heer) Nath., *Sequoia microlepis* Sveshn., *Taxodium* ex gr. *dubium* Heer, *Glyptostrobus* ex gr. *nordenskioldii* (Heer) Brown, *Libocedrus catenullata* Bell., *Thuja cretaceae* (Heer) Newb., *Athrotaxopsis grandis* Font. Angiospermae: *Nelumbo* sp., *Nelumbites minimus* Vachr., *Trochodendroides arctica* (Heer) Berry, *"Platanus"* ex gr. *raynoldsii* Newb., *Carpinus* sp., *Myrica* sp., *Nyssa punctata* Heer, *Nyssoidea mongolica* Krassil., *Bothrocaryum gobiensis* Krassil., *Quereuxia rotundifolia* Golovn., *Potamogeton* sp., *Phragmites* ex gr. *alaskana* Heer, *Arundo* ex gr. *goeppertii* (Muenst.) Heer, *Zingiberopsis* sp., *Lemna* sp.

[1] New taxa encountered in the studied samples are marked by asterisks.

CONCLUSION

The reported results characterize the Late Cretaceous floras collected from 11 localities in the southern Gobi. Their stratigraphic position is established based on succession of faunal and floral assemblages. The Aptian–Albian, Cenomanian–Turonian, Santonian–Campanian, and Maastrichtian plant assemblages are discriminated. They predominantly consist of aquatic, riparian, terrestrial arboreal and fruticose plant taxa, some of which are found for the first time, e.g., new genera and species of fungi, Isoetales, and angiosperms. In the Nemegt Formation, abundant and diverse organic remains are found for the first time in association with fossil ostracodes, mollusks, conchostracans, fishes, insects, turtles, lizards, birds, dinosaurs, and mammals. The above taphocoenoses are used to reconstruct the past landscapes and climatic conditions in the study region, where *Araucaria* and *Ginkgo* forests were widespread in the Late Cretaceous. Systematic description of a new *Araucaria* species is presented below.

Araucaria gobiensis Makul., sp. nov.

Plate I, figs. 1–4; Plate II, figs. 1–6.

Holotype: Paleontological Institute, Russian Academy of Sciences, no. 4385/1; completely mineralized, well-preserved cone; southern Gobi, Shiregin-Gashun depression, Tsunzh region, Bain-Shire Formation; Cenomanian–Turonian.

Material: mineralized cones, intact and fragmented, over 15 specimens, collection no. 4385.

Diagnosis. Cones ovoid or elongated-ovoid in shape, 5–10 cm long and 3–5 cm wide. Bract scales rhombic, ligulated, imbricating, helically arranged. Seeds elongated, predominantly monostichous, set in ovuliferous scale axils, inversely cuneated, arrangement radial.

Description. Well-preserved cones from collection are ovoid to elongated-ovoid in shape, 5–10 cm long and 3–5 cm wide. Bract scales are imbricating, heli-

Plate I

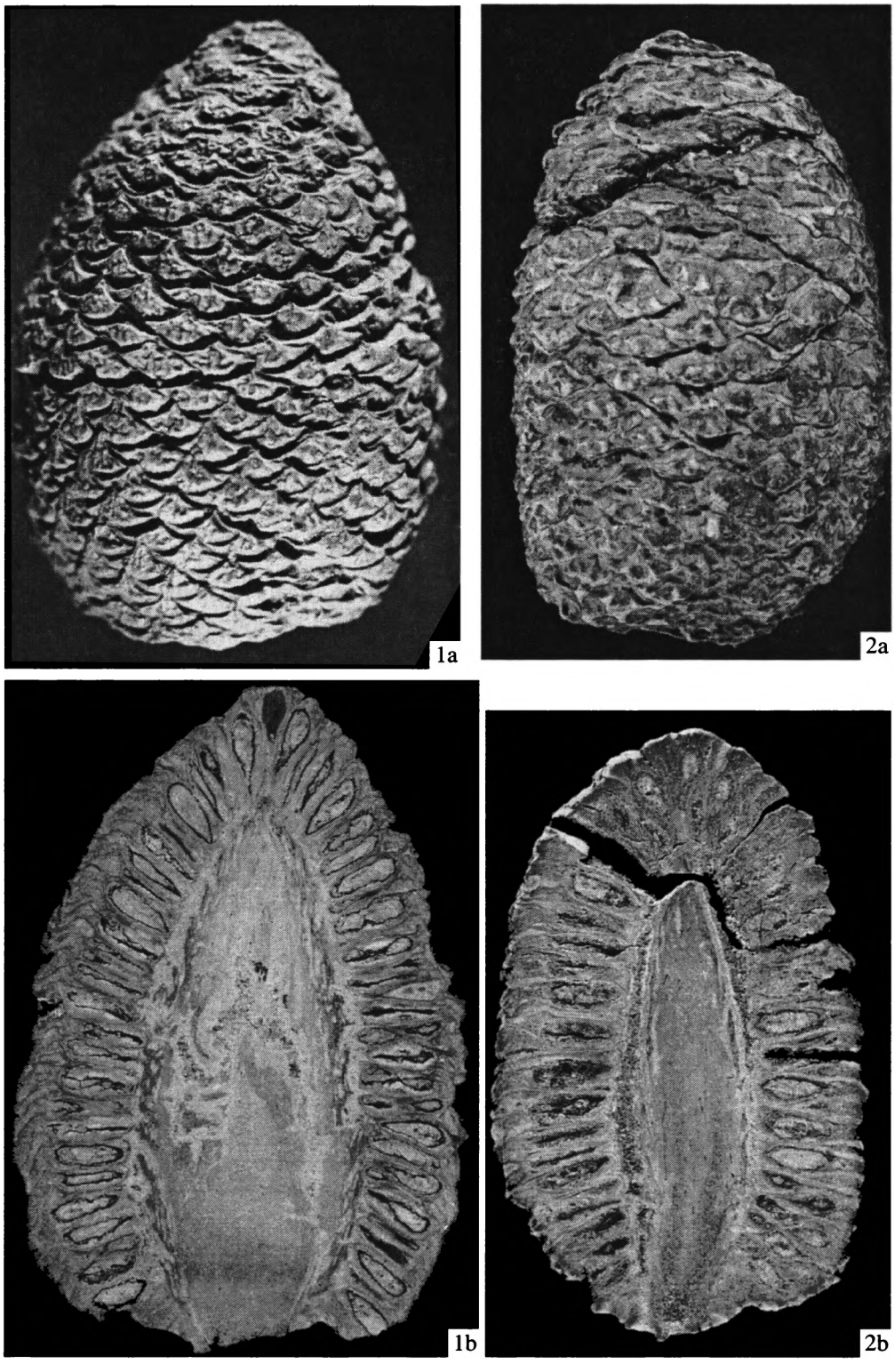


Plate I. *Araucaria gobiensis* Makul., sp. nov., southern Gobi, Shiregin-Gashun, Bain-Shire Formation, Cenomanian–Turonian: (1a) lignitized whole cone, holotype, Paleontological Institute RAS, 4385/1, 1×1; (1b) longitudinal section of the cone with seeds, 1×1. (2a) lignitized whole cone, paratype, Paleontological Institute RAS, 4385/2, 1×1; (2b) longitudinal section of the cone with seeds, 1×1.

Plate II

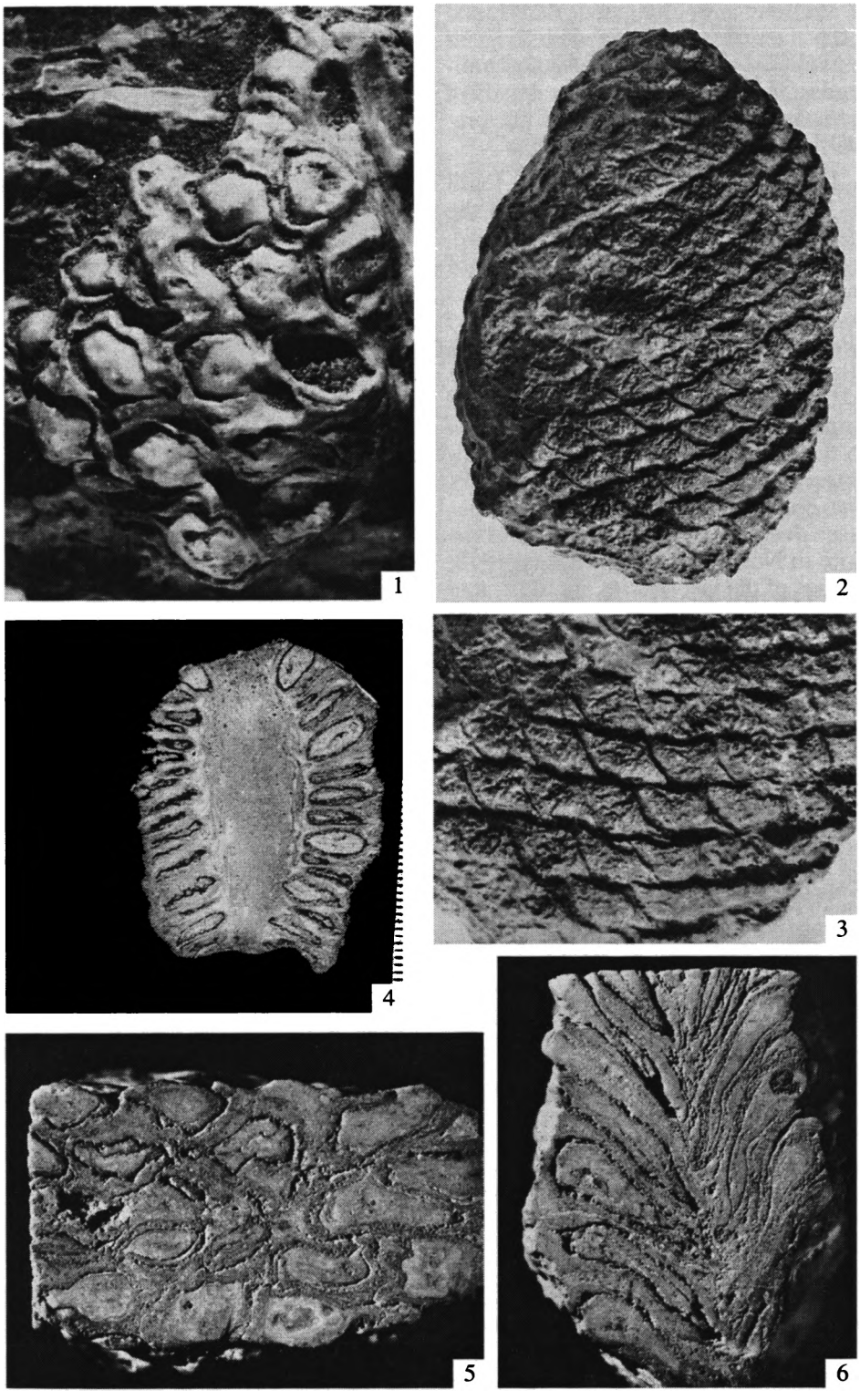


Plate II. *Araucaria gobiensis* Makul., sp. nov., southern Gobi, Shiregin-Gashun, Bain-Shire Formation, Cenomanian–Turonian: (1) cone fragment with seeds, Paleontological Institute RAS, 4385/4; (2) flattened whole cone, Paleontological Institute RAS, 4385/3; (3) detailed structure of bract scales, Paleontological Institute RAS, 4385/3, 1×2; (4) longitudinal section of small cone with seeds arranged in one row, Paleontological Institute RAS, 4385/5. (5, 6) cross and longitudinal sections of non-mature cone, Paleontological Institute RAS, 4385/6.

cally arranged, rhombic in shape, with a minor ligula. Visible in cross sections are elongated rachis and numerous seeds 0.5–1-cm long, arranged in axils of ovuliferous scales solitary or distichously. An acuminate edge is pointed to the cone center. Other details of outer and internal structure of the cones are not preserved in available specimens.

Comparison. In published descriptions of fossil *Araucaria* cones, I did not find forms similar to the described specimens, which differ from others in size, radial, distichous or monostichous arrangement of seeds in scale axils, and in acuminate seed edges pointed to rachis. In *Araucaria longifolia* (Lesqu.) Brown from the Paleocene of the Rocky Mountains in North America (Brown, 1962, p. 48, Pl. 13), seeds are monostichous and lack acuminate edges. The described cones similarly differ with from other fossil *Araucaria* species present in the Jurassic, Cretaceous, and Paleogene floras of Eurasia and North America. For instance, they are greater than cones of *Araucaria mirabilis* (Spegazzini) Windhausen described from the Jurassic of the Cerro Quadrado site in North America (Stockey, 1978, Pl. 1–6). Similar cones of the last species are illustrated in popular books on paleobotany by Thomas (1981) and Stewart (1983).

Distribution: southern Gobi, Shiregin-Gashun depression, Tsunzh region, Bain-Shire Formation, Cenomanian–Turonian.

ACKNOWLEDGMENTS

I am grateful to Prof. G.G. Martinson for cone specimens of excellent preservation donated for this study and to late Dr. P.I. Dorofeev and V.A. Vakhrameev, the Corresponding Member of Russian Academy of Sciences, who suggested affinity of cones with the genus *Araucaria.*

Reviewers M.A. Akhmet'ev and M.P. Dolugenko

REFERENCES

1. V. R. Alifanov, "The Upper Cretaceous Lizard Fauna from Mongolia and Problem of the First Inter-American Contact," Paleontol. Zh. **27** (3), 79–84 (1993) [Paleontol. J. **27** (3), 100 (1993a)].
2. V. Alifanov, "Some Peculiarities of the Cretaceous and Paleogene Lizard Faunas of the Mongolian People's Republic," Kaupia Darmstadter Beitrage zur Naturgeschichte **3**, 9–13 (1993b).
3. R. Barsbold, *Upper Cretaceous Biostratigraphy and Fresh-Water Mollusks of the Mongolian Gobi* (Nauka, Moscow, 1972) [in Russian].
4. R. Barsbold, *Theropods of Mongolia* (Nauka, Moscow, 1983) [in Russian].
5. R. S. Bellen, "On the Presence of *Atopochara* Peck in the Lower Cretaceous of the Sebel Ansarych, Syria," Micropalaeontologist **2** (4), 16 (1948).
6. Ch. Berkey and F. K. Morris, "Geology of Mongolia," in *Natural History of Central Asia* (Am. Mus. Natur. Hist., New York, 1927), Vol. 2.
7. M. O. Borsuk, "Order Isoetales," in *Fundamentals of Paleontology*, Ed. by V. A. Vakhrameev, G. P. Radchenko, and A. L. Takhtadzhan (Akad. Nauk SSSR, Moscow, 1963), pp. 461–463 [in Russian].
8. R. W. Brown, "Paleocene Flora of the Rocky Mountains and Great Plains," US Geol. Surv. Prof. Pap. **375**, 1–119 (1962).
9. M. E. I. Chandler, *The Lower Tertiary of Southern England. 1. Paleocene Floras. London Clay Flora* (Brit. Mus. Nat. History, London, 1961).
10. J. A. Doyle and L. J. Hickey, "Coordinated Evolution in Potomac Group Angiosperm Pollen and Leaves," Am. J. Botany **59**, 1–660 (1972).
11. J. A. Doyle and L. J. Hickey, "Pollen and Leaves from the Mid-Cretaceous Potomac Group and Their Bearing on Early Angiosperm Evolution," in *Origin and Early Evolution of Angiosperms* (Columbia Univ. Press, New York, 1976), pp.139–206.
12. I. A. Efremov, "Some Remarks on Evolution of Dinosaurs," Tr. Paleontol. Inst. Rus. Acad. Sci. **48**, 126–141 (1954).
13. R. H. Eyde and E. S. Barghoorn, "Morphological and Paleobotanical Studies of the Nyssaceae. 2. The Fossil Record," J. Arnold Arbor. **44**, 328–377 (1963).
14. *Fundamentals of Paleontology. Gymnosperms and Angiosperms*, Ed. by V. A. Vakhrameev, G. P. Radchenko, and A. L. Takhtadzhan (Akad. Nauk SSSR, Moscow, 1963) [in Russian].
15. R. Gradzinski, "Sedimentation of Dinosaur-Bearing Upper Cretaceous Deposits of the Nemegt Basin, Gobi Desert," Palaeontol. Polon. **21**, 147–229 (1970).
16. L. J. Hickey and J. A. Doyle, "Early Cretaceous Fossil Evidence for Angiosperm Evolution," Bot. Rev. **43**, 3–104 (1977).
17. A. Hollick, "The Upper Cretaceous Floras of Alaska," US Geol. Surv. Prof. Pap. **123**, 1–121 (1930).
18. T. Jerzykiewicz and D. A. Russell, "Late Mesozoic Stratigraphy and Vertebrates of the Gobi Basin," Cretaceous Res. **12**, 345–377 (1991).
19. J. Karczewska and M. Ziembinska-Tworzidlo, "Upper Cretaceous Charophyta from the Nemegt Basin, Gobi Desert," Paleontol. Polon. **21**, 122–144 (1970).
20. F. Kirchheimer, *Palaobotanische Beitrage zur Kenntnis des Alters deutscher Braunkohlenschichten. 4 Braunkohle* (Halle, Knapp, 1938).
21. F. Kirchheimer, "Über *Steinhauera subglobosa* Presl. und die Reste von *Liquidambar.* Fruchstanden aus Tertiar Mitteleuropas", Neues Jahrb. Mineral. Geol. Palaeontol. **B**, 216–225 (1943).
22. F. Kirchheimer, *Die Laubgewachse der Braunkohlenzeit* (Halle, Knapp, 1957).
23. E. Knobloch, "On Some Primitive Leaves from the Upper Cretaceous of the Bohemian Massif", Palaeontographica **166**, 83–98 (1978).
24. E. D. Konzhukova, "New Fossil Crocodiles from Mongolia", Tr. Paleontol. Inst. Rus. Acad. Sci. **48**, 18–24 (1954).
25. V. A. Krassilov, *Early Cretaceous Flora of Southern Primorie and Its Significance for Stratigraphy* (Nauka, Moscow, 1967) [in Russian].

26. V. A. Krassilov, *Tsagayan Flora of the Amur Region* (Nauka, Moscow, 1976) [in Russian].
27. V. A. Krassilov, "The Origin of Angiosperms," Bot. Rev. **43** (1), 143–176 (1977).
28. V. A. Krassilov, *Cretaceous Flora of Sakhalin* (Nauka, Moscow, 1979) [in Russian].
29. V. A. Krassilov, "Fossil Plants of Manlai," in *Early Cretaceous Manlai Lake*, Ed. by N. S. Kalugina (Nauka, Moscow, 1980), pp. 40–42 [in Russian].
30. V. A. Krassilov, "Early Cretaceous Flora of Mongolia," Palaeontographica **181**, 1–43 (1982).
31. V. A. Krassilov, "Floral Alteration at the Cretaceous–Paleogene Boundary in the Kavalerovo region, Primorie," in *Cenozoic of the Far East*, Ed. by V. A. Krassilov and R. S. Klimova (Far East Divis. RAS, Vladivostok, 1989a), pp. 34–37 [in Russian].
32. V. A. Krassilov, *Origin and Early Evolution of Flowering Plants* (Nauka, Moscow, 1989b) [in Russian].
33. V. A. Krassilov and N. M. Makulbekov, "Maastrichtian Aquatic Plants from Mongolia," Paleontol. J. **29** (2A), 119–140 (1995).
34. V. A. Krassilov and N. M. Makulbekov, "The First Finding of Gastromycetes in the Cretaceous of Mongolia," Paleontol. Zh. **4**, 103–106 (2003) [Paleontol. J. **4**, 439–442 (2003)].
35. V. A. Krassilov and G. G. Martinson, "Fruits from the Upper Cretaceous Sediments of Mongolia," Paleontol. Zh. **1**, 113–120 (1982).
36. N. P. Kyansep-Romashkina, "Early Cretaceos Charophytes of the Fergana and Tajik Depressions," in *Continental Formations of the Eastern Central Asia and Kazakhstan*, Ed. by N. N. Barkhatova (Nauka, Moscow, 1969), pp. 52–68 [in Russian].
37. N. P. Kyansep-Romashkina, "Some Late Jurassic and Cretaceous Charophytes of Mongolia," in *Fossil Fauna and Flora of Mongolia*, Ed. by N. N. Kramarenko (Nauka, Moscow, 1975), pp. 181–204 [in Russian].
38. N. P. Kyansep-Romashkina, "Charophyte Distribution in the Mesozoic Lakes of Mongolia and Conditions of Their Habitats," in *Mesozoic Lakes of Mongolia*, Ed. by G. G. Martinson (Nauka, Leningrad, 1982), pp. 158–193 [in Russian].
39. V. M. Lopatin, "Lower Cretaceous Stratigraphy of the Shavokhty Depression in Southeastern Mongolia," in *Early Cretaceous Manlai Lake*, Ed. by N. S. Kalugina (Nauka, Moscow, 1980), pp. 6–19 [in Russian].
40. E. A. Maleev, "Some Remarks on Geological Age and Stratigraphic Distribution of Ankylosaurs in Mongolia," Dokl. Akad. Nauk SSSR **85**, 893–896 (1952a).
41. E. A. Maleev, "New Ankylosaur Family from the Upper Cretaceous of Mongolia," Dokl. Akad. Nauk SSSR **87**, 131–134 (1952b).
42. G. G. Martinson, "On the Principles of Stratigraphy and Correlation of the Mesozoic Continental Formations in Mongolia," in *Mesozoic Stratigraphy of Mongolia*, Ed. by G. G. Martinson (Nauka, Moscow, 1975), pp. 7–24 [in Russian].
43. G. G. Martinson, *Late Cretaceous Mollusks of Mongolia* (Nauka, Moscow, 1982) [in Russian].
44. G. G. Martinson, A. V. Sochava, and R. Barsbold, "On the Stratigraphic Subdivision of the Upper Cretaceous of Mongolia," Dokl. Akad. Nauk SSSR **189**, 1081–1084 (1969).
45. F. K. Morris, "Central Asia in Cretaceous Time," Bull. Geol. Soc. Am. **47**, 1477–1533 (1936).
46. E. A. Musacchio, "Datos Paleobiogeograficos de Algunas Associaciones de Foraminiferos, Ostracodos y Carofitas del Jurasico Medio y el Cretacico Inferior de Argentina," Ameghiniana, Revista Asoc. Paleontol. Argentina **XYI** (3–4), 247–271 (1979).
47. M. S. Nagibina, V. F. Shuvalov, and G. G. Martinson, "Major Features of Stratigraphy and History of Evolution of the Mesozoic Structures in Mongolia," in *Major Geological Problems of Mongolia* (Nauka, Moscow, 1977), Vol. 22, pp. 76–91 [in Russian].
48. R. E. Peck, "North American Mesozoic Charophyta," US Geol. Surv. Prof. Pap., No. 294-A, 1–44 (1957).
49. K. Rasky, *Fossile Charophyten-Fruchte aus Ungarn* (Ungarn Naturwiss. Mus. Monogr., Budapest, 1945), Vol. 2.
50. V. A. Samylina, *Cretaceous Flora of Omsukchan* (Nauka, Leningrad, 1976) [in Russian].
51. A. C. Seward, *Fossil Plants. 2* (Cambridge Univ. Press, Cambridge, 1910).
52. A. C. Seward, "The Cretaceous Plant-Bearing Rocks of Western Greenland," Phil. Trans. Roy. Soc. London **215** (B), 57–175 (1926).
53. V. F. Shuvalov, "Major Stages of Mesozoic Lake Evolution In Mongolia," in *Proceedings of the Third All-Union Symposium on History of Lakes, Leningrad, Russia, 1975* (Nauka, Leningrad, 1975), p. 32 [in Russian].
54. V. F. Shuvalov, "Late Cretaceous Evolution of Topography," in *Geomorphology of Mongolian People's Republic*, Ed. by N. A. Florensov and S. S. Korzhuev (Nauka, Moscow, 1982), pp. 217–223 [in Russian].
55. V. F. Shuvalov and V. M. Chkhikvadze, "New Records on Late Cretaceous Turtles of Southern Mongolia," in *Fossil Fauna and Flora of Mongolia*, Ed. by N. N. Kramarenko (Nauka, Moscow, 1975), pp. 214–229 [in Russian].
56. A. V. Sochava, "Upper Cretaceous Stratigraphy and Lithology of Southern Mongolia," in *Mesozoic Stratigraphy of Mongolia*, Ed. by G. G. Martinson (Nauka, Leningrad, 1975), pp. 113–182 [in Russian].
57. E. S. Stankevich, "Freshwater Ostracodes from the Bain-Shire Formation of the Southwestern Trans-Altai Gobi," in *Limnobios of the Ancient Lakes in Eurasia*, Ed. by G. G. Martinson (Nauka, Leningrad, 1979), pp. 65–71 [in Russian].
58. E. S. Stankevich, "Late Cretaceous Ostracodes and Their Habitats," in *Mesozoic Lakes of Mongolia*, Ed. by G. G. Martinson (Nauka, Leningrad, 1982), pp. 145–157 [in Russian].
59. W. N. Stewart, *Paleobotany and the Evolution of Plants* (Cambridge Univ. Press, London, 1983).
60. R. A. Stockey, "Reproductive Biology of Cerro Cuadrado Fossil Conifers: Ontogeny and Reproductive Strategies in *Araucaria mirabilis* (Spegazzini) Windhausen," Palaeontographica **166**, 1–15 (1978).
61. K. Suzuki, "Freshwater Shells from the Cretaceous Sungari Series in Central Manchoukuo", J. Fac. Sci. Imp. Univ. Tokyo **6** (2), 12–17 (1942).

62. A. L. Takhtadzhyan, *Origin and Dispersal of Flowering Plants* (Nauka, Leningrad, 1970) [in Russian].

63. B. Thomas, *The Evolution of Plants and Flowers* (Madrid, 1981).

64. I. E. Turishchev, "New Records on the Cretaceous Stratigraphy of Southeastern Mongolia," Geol. Sb. VNIGRI **3** (1), 99–107 (1955).

65. V. A. Vakhrameev, *Jurassic and Cretaceous Floras and Climates of the Earth* (Nauka, Moscow, 1988) [in Russian].

66. V. A. Vakhrameev, *Mesozoic Paleofloristics, Phytogeography, and Climates* (Nauka, Moscow, 1990) [in Russian].

67. V. A. Vakhrameev and I. Z. Kotova, "Ancient Angiosperms and Associated Plants from the Lower Cretaceous Sediments of Transbaikalia", Paleontol. Zh. **4**, 101–109 (1977).

68. V. G. Vasil'ev, I. S. Volkhonin, G. L. Grishin, A. Kh. Ivanov, N. A. Marinov, K. B. Mokshantsev, *Geology of Mongolian People's Republic (Stratigraphy and Tectonics)* (Gostoptekhizdat, Leningrad, 1959) [in Russian].

69. T. Ch. Yen, "Non-Marine Mollusca of Late Cretaceous Age from Wyoming, Utah, and Colorado," US Geol. Surv. Prof. Pap., No. 254-B (1964).

70. Zhen Wang, "Cretaceous Charophytes from the Jangtze-Han River Basin with a Note on the Classification of Porocharaceae and Characeae," Mem. Nanjing Inst. Geol. Paleontol. Sinica **5** (9), 61 (1978).

Stratigraphy and Geological Correlation, Vol. 12, No. 6, 2004, pp. 603–636. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 12, No. 6, 2004, pp. 69–102.
Original Russian Text Copyright © 2004 by Olfer'ev, Alekseev, Beniamovskii, Vishnevskaya, Ivanov, Pervushov, Sel'tser, Kharitonov, Shcherbinina.
English Translation Copyright © 2004 by MAIK "Nauka/Interperiodica" (Russia).

The Mezino-Lapshinovka Reference Section of the Upper Cretaceous and Problems of Santonian–Campanian Boundary in Saratov Area near the Volga River

A. G. Olfer'ev*, A. S. Alekseev, V. N. Beniamovskii***, V. S. Vishnevskaya****, A. V. Ivanov*****, E. M. Pervushov******, V. B. Sel'tser*****, V. M. Kharitonov*****, and E. A. Shcherbinina*****

* *Paleontological Institute, Russian Academy of Sciences, ul. Profsoyuznaya 123, Moscow, 117647 Russia*
** *Moscow State University, Leninskie gory, Moscow, Russia*
*** *Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia*
**** *Institute of the Lithosphere of Marginal Seas, Staromonetnyi per 22, Moscow, 119180 Russia*
***** *Research Institute, Saratov State University, Saratov, Russia*
****** *Saratov State University, Saratov, Russia*

Received August 10, 2003

Abstract—Results of multidisciplinary study in the Upper Cretaceous reference section and characteristics of the Mezino-Lapshinovka Formation stratotype are presented. The late Santonian age of the formation is substantiated based on the analyzed organic remains. The formation is considered to be a stratigraphic equivalent of the *Pteria* Beds, the age of which was animatedly discussed during over a century. The age of the Mozhzhevelovyi Ovrag Formation that underlies the Mezino-Lapshinovka Formation and yields foraminifers, radiolarians, and calcareous nannoplankton is also discussed. The ammonite assemblage of the lower upper Campanian first discovered in the basal part of the Ardym Formation of the Volga region is characterized.

Key words: Coniacian, Santonian, and Campanian stages, Mozhzhevelovyi Ovrag, Mezino-Lapshinovka, Rybushka, and Ardym formations, ammonite, belemnites, bivalves, foraminifers, radiolarians, calcareous nannoplankton, zonal subdivision.

Contributing to elaboration of the Upper Cretaceous stratigraphic scale for the East European platform, geologists from the Research Institute of Geology and geological faculty of the Saratov State University took active part in defining local stratigraphic units (formations) in lower and middle courses of the Volga River, where they were out of practical use until recently. Views of Saratov geologists on stratigraphic ranges, lithology, and nomenclature of defined formations are expounded in publications of the last decade (Ivanov, 1995; Popov and Ivanov, 1996, 1997; Ivanov and Popov, 1998; Ivanov and Pervushov, 1998; Pervushov *et al.*, 1998a, 1998b, 1998c). The last version of stratigraphic scheme elaborated for the Saratov region is included, as a main constituting part, into the Upper Cretaceous stratigraphic scheme of the East European platform, which was accepted at the Interdepartmental regional stratigraphic meeting and then approved by the Interdepartmental Stratigraphic Committee of Russia in February of 2001. The scheme includes 13 stratigraphic units: Melovatka, Bannovka, Vol'sk, Mozhzhevelovyi Ovrag, Mezino-Lapshinovka, synchronous Rybushka and Pudovkino, Ardym, synchronous Tereshka and Nalitovka, Lokh, Nikolaevka, and Karamysh formations. All these units, except for the Tereshka Formation previously described by V.V. Butsura as Tereshka Beds and for the Nalitovka Formation first defined by G.A. Zhukova, were originally defined by E.M. Pervushov, A.V. Ivanov, and E.V. Popov. They are briefly characterized in "The abridged atlas of Late Cretaceous bivalves from the southeastern East European platform" (Yakushin and Ivanov, 2001), although the descriptions presented are very simplified and do not satisfy requirements of the Stratigraphic Code (1992, p. 39).

This work is dedicated to the multidisciplinary characterization of the Mezino-Lapshinovka Formation stratotype described by Ivanov, Olfer'ev, Pervushov, Sel'tser, and Kharitonov. Organic remains collected during field works were studied by Sel'tser (ammonoids), Ivanov, Pervushov, Kharitonov (bivalves), Beniamovskii (foraminifers), Vishnevskaya (radiolarians), and Shcherbinina (nannofossils). Alekseev who examined terrigenous fraction and composition of bioclasts in samples collected for micropaleontological studies was a coordinator of the work.

The study of the Mezino-Lapshinovka Formation stratotype and layers above and below it enabled a new interpretation of the debatable Santonian/Campanian boundary in the Volga River region and of the *Pteria* Beds age. The *Pteria* Beds correspond to sediments with abundant shells of bivalves *Oxytoma (Hypoxytoma) tenuicostata* (Roemer, 1841) first attributed to the genus *Avicula*. Subsequently, this species was referred to the subgenus *Pteria (Oxytoma)* (Woods, 1905) that was included afterward into the genus *Oxytoma* Meek, 1964 (Glazunova, 1960).

SECTION DESCRIPTION

The Upper Cretaceous section near the village of Mezino-Lapshinovka is examined in the wall of abandoned quarry in the eastern outskirt of the village. The site is in the Tatishchev district of the Saratov region approximately 40 km north-northwest of the regional center (Fig. 1). The following beds are exposed in the quarry wall from its base to the upper edge (Figs. 2, 3).

The Mozhzhevelovyi Ovrag Formation

(1) Interval 13.6–13.9 m. Marl, gray to yellowish gray, micaceous, glauconitic. Glauconite occurring as fine sand-sized grains is regularly scattered in the rock as a rule, although it is locally concentrated in separate lenses and powdery accumulations. The uppermost part encloses distinct inclined and subvertical fucoids 1.0 to 1.5 cm in diameter filled in with silty material enriched in glauconite. The apparent thickness is 0.3 m.

(2) Interval 12.4–13.6 m. Fine-grained quartz–glauconite sand, light and greenish gray near the top to dark gray and bright green at the base of the layer, with the glauconite content increasing downward. The sand is calcareous, silty near the top, bioturbated; fucoids are commonly colored yellow or red because of filling jarosite and Fe hydroxides. The middle and lower parts of the layer contain subautochthonous remains of fossil sponges *Sororistrips* sp. and *Plococyphia* sp. with associated silicification of surrounding sediments, as well as rare belemnite rostra and phosphorite nodules. The transition to overlying sediments is gradual. The thickness is 1.2 m.

(3) Interval 10.7–12.4 m. Siliceous marl, light gray, intensely silicified in the lower and upper parts, grading into dark gray, laterally sustained opoka. In the middle part, marl is sandy, fine-grained, bearing quartz, glauconite, and rounded lens-like inclusions of jarosite and Fe hydroxides. Psammitic material is concentrated in lenses determining bedding patterns of the rock. Large thin-walled shells of *Oxytoma tenuicostata* (Roem.) and *Liostrea wegmaniana* (d'Orb.) are scattered throughout the unit. The bed lower part yields rare small rostra of belemnite *Actinocamax* sp. and exhibits crustacean burrows with fish scale at the bottom and fucoids. The transition to overlying sediments is gradual. The thickness is 1.7 m.

(4) Interval 10.5–10.7 m. Calcareous clay, gray to light gray, siliceous, flaggy, containing shells of *Oxytoma tenuicostata* (Roem.) and *Liostrea wegmaniana* (d'Orb.). The transition to overlying sediments is gradual. The thickness is 0.2 m.

(5) Interval 10.0–10.5 m. Opoka, light gray with brown spots, ferruginous, bioturbated, enclosing shells of oysters *Liostrea wegmaniana* (d'Orb.) and *Gryphaeostrea lateralis* (Nilss.). The transition to overlying sediments is gradual. The thickness is 0.5 m.

(6) Interval 9.3–10.0 m. Clay, gray, with a greenish tint and rusty brown spots at the top, calcareous, irregularly silicified; the silicification degree increases upward. Sediments yield shells of *Oxytoma tenuicostata* (Roem.), *Liostrea wegmaniana* (d'Orb.), and *Acutostrea acutirostris* (Nills.). The thickness is 0.7 m.

The Mezino-Lapshinovka Formation

(7) Interval 8.8–9.3 m. Fine-grained glauconite sand, light gray with greenish tint and rusty brown ferruginous spots, calcareous, containing rare phosphorite nodules up to 5 cm across, rostra of belemnites *Belemnitella praecursor* Stoll., *Actinocamax verus fragilis* Arkh., and *Paractinocamax grossouvrei depressus* (Andreae), and small shark teeth. Both contacts are distinct. The thickness is 0.5 m.

(8) Interval 3.8–8.8 m. Alternating diatomaceous marls and opokas connected by gradual transitions. Marls are light gray, with abundant rusty brown spots of Fe-hydroxides, containing glauconite grains in the upper part of the layer, and yielding scarce rostra of belemnites *Actinocamax verus fragilis* Arkh. and *Belemnitella* sp. Opokas are gray to dark gray, mottled because of irregular silicification, compact, resonant, characterized by angular fracture, and enclosing *Oxytoma tenuicostata* (Roem.), *Sphenoceramus* cf. *pinniformis* (Willet), *S. patootensis* (Lor.), *Liostrea wegmaniana* (d'Orb.), *Gryphaeostrea lateralis* (Nills.), *Acutostrea acutirostris* (Nills.), and *Monoticulina hippopodia* (Nills.). The hardground indicating a hiatus at the top is represented by dark gray to black coarse-clastic opoka 0.3 m thick, enclosing numerous crustacean burrows with fish scale at their bottoms. Material filling fucoids contains quartz and glauconite grains derived from the overlying bed. The hardground opoka yields usually isolated and horizontally arranged valves of *Oxytoma tenuicostata* (Roem.) up to 3–4 cm across. The thickness is 0.5 m.

The Rybushka Formation

(9) Interval 2.5–3.8 m. Fine-grained sand, light gray with greenish tint, glauconitic, highly calcareous, sometimes grading into sandy marl, with thin lenticular bedding, phosphorite nodules up to 5 cm across and similarly sized rusty brown ferruginous concretions. The bed is intensely bioturbated, particularly in the lower part. Abundance of silty material increases

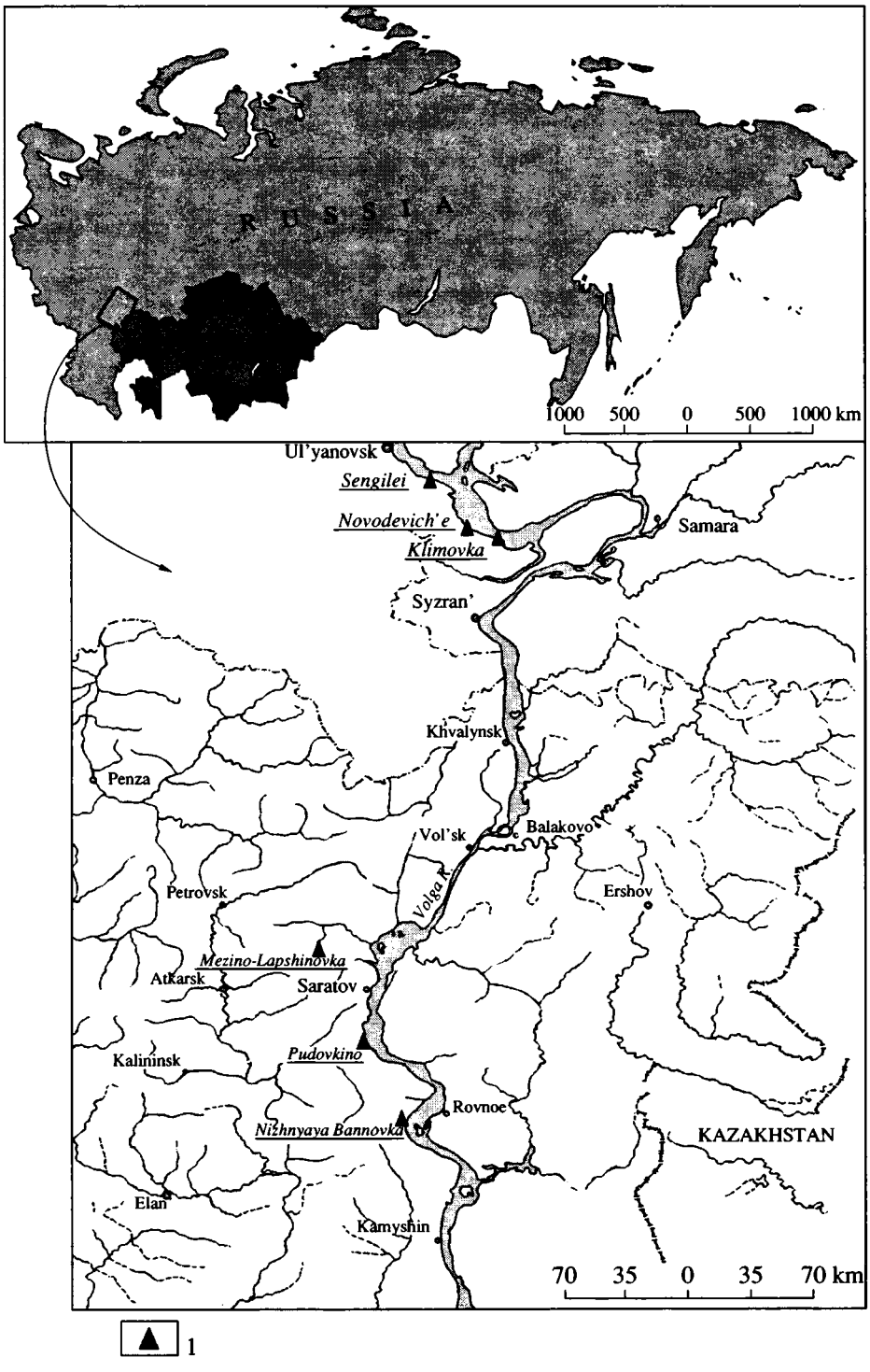


Fig. 1. Localities of the Mezino-Lapshinovka (1) and other reference sections of "*Pteria* Beds."

toward the base, where sand is colored pale to grayish brown. In the middle part of the bed, there are abundant subhorizontally arranged rostra of belemnites *Belemnellocamax mammillatus mammillatus* (Nills.) and *B. mammillatus volgensis* Najd., remains of siliceous sponges *Rhizopoterion cervicorne* (Goldf.), fragments of cups belonging to other ventriculitids, and valves of oyster *Gryphaeostrea lateralis* (Nills.). The lower part of the bed yields abundant isolated valves of *Oxytoma tenuicostata* (Roem.), *O. intermedia* A. Ivanov, and *Microchlamys pulchella* (Nills.). The transition to overlying sediments is gradual. The thickness is 1.3 m.

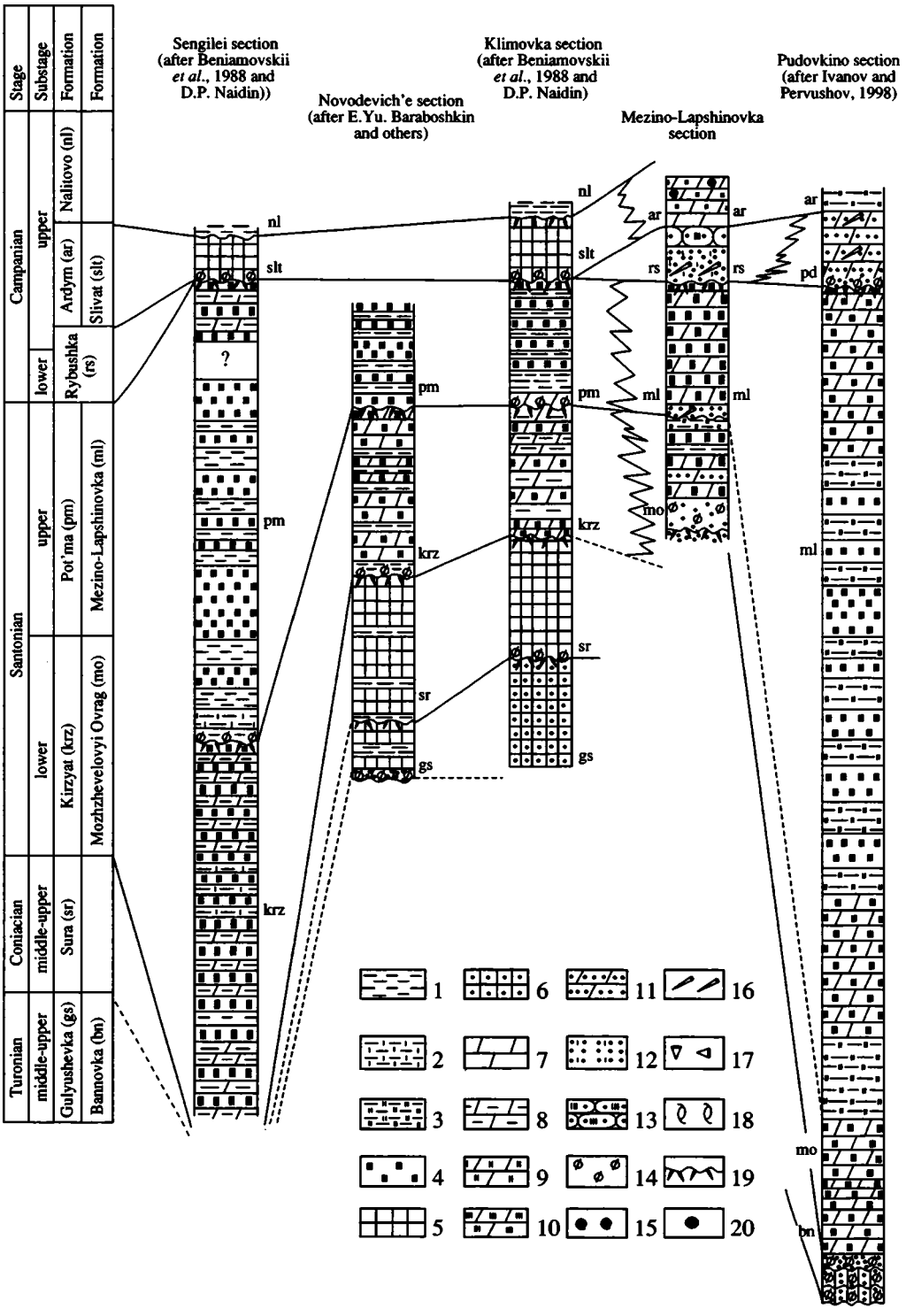


Fig. 2. Correlation of the Turonian–Campanian reference sections in the Ul'yanovsk–Saratov region, right side of the Volga River: (1) clay; (2) calcareous clay; (3) siliceous clay; (4) opoka; (5) chalk; (6) sandy chalk; (7) marl; (8) clayey marl; (9) tripoli marl; (10) siliceous marl; (11) sandy marl; (12) calcareous sand; (13) siliceous sandstone; (14) inclusions of phosphorite nodules. Fossils: (15) ammonites, (16) belemnite rostra, (17) sponges, (18) bivalves; (19) unconformities or hardgrounds; (20) levels with organic remains. Indices of local stratigraphic units (formations): (gs) Gulyushevka, (bn) Bannovka, (sr) Sura, (krz) Kirzyat, (mo) Mozhzhevelovyi Ovrag, (pm) Pot'ma, (ml) Mezino-Lapshinovka, (rs) Rybushka, (pd) Pudovkino, (ar) Ardym, (Slt) Slivat, (nl) Nalitovo.

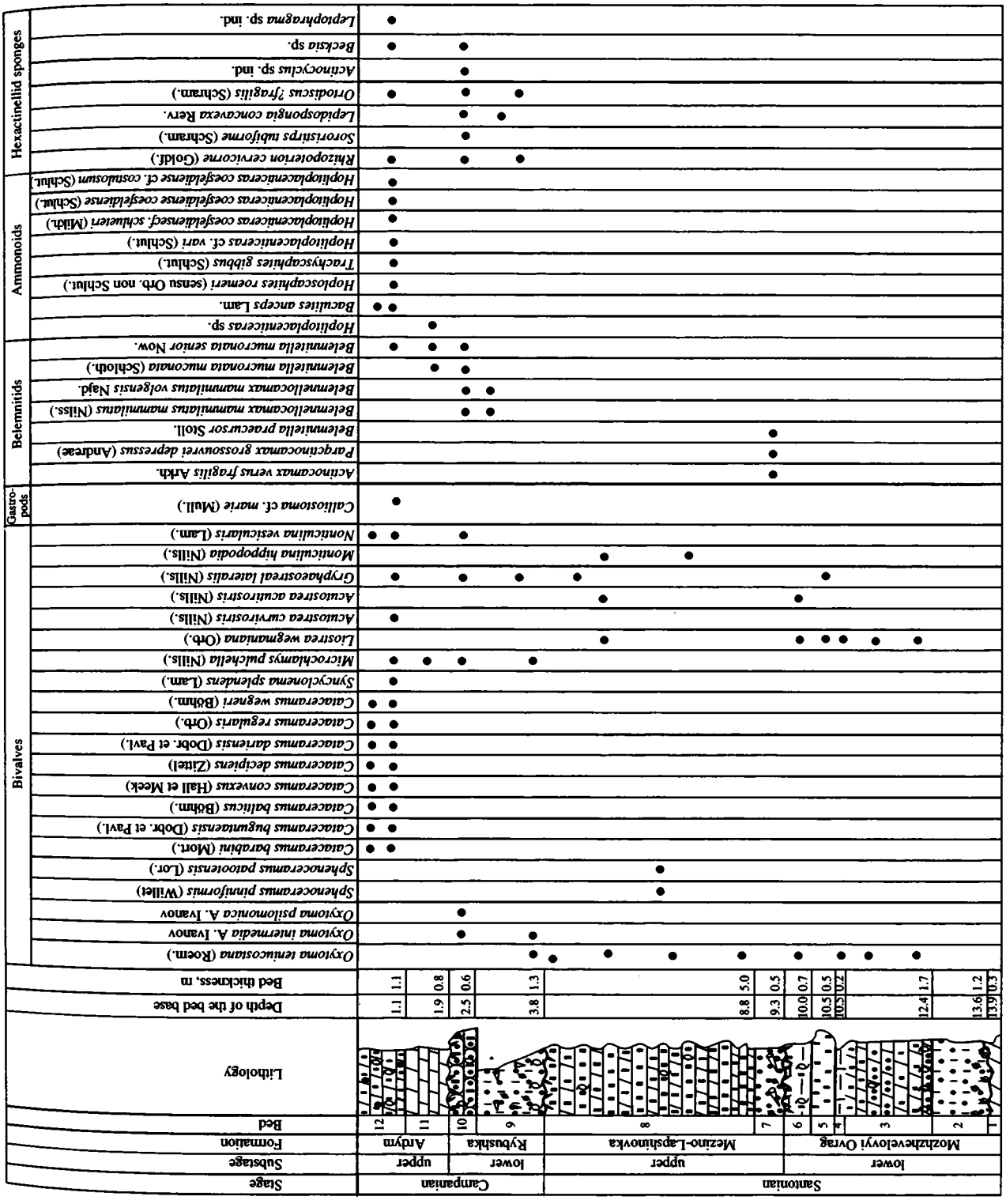


Fig. 3. Distribution of invertebrate remains in the Mezino-Lapshinovka section (legend as in Fig. 2).

(10) Interval 1.9–2.5 m. Fine- to medium-grained quartz–glauconite sand, greenish gray, irregularly silty, with siliceous cement of the basal type near the base and interstitial at the top of the bed. Near the base, there are ferruginous concretions 2–5 cm across, partly developed after flat fragments of siliceous sponges. The bed encloses accumulations of intact shells and separate valves of oyster species *Monticulina vesicularis* (Lam.), *Gryphaeostrea lateralis* (Nills.), pectinids *Oxytoma intermedia* A. Ivanov, *O. psilomonica* A. Ivanov, and *Microchlamys pulchella* (Nills.), rostra of belemnites *Belemnellocamax mammillatus mammillatus* (Nills.), *B. mammillatus volgensis* Najd., *Belemnitella mucronata mucronata* (Schloth.), *B. mucronata senior* Now., and remains of sponges *Rhizopoterion cervicorne* (Goldf.), *Sororistirps tubiforme* (Schram.), *Actinocyclus* sp., *Becksia* sp., *Ortodiscus* sp., and *Lepidospongia* sp. Being well resistant to erosion, the bed forms a distinct projection in the quarry wall. Sandstone is best cemented near the upper undulating and sharp contact with overlying sediments. The thickness is 0.6 m.

The Ardym Formation

(11) Interval 1.1–1.9 m. Chalky marl, light gray to almost white, vaguely flaggy, with nest-shaped glauconite accumulations at the base. The bed yielded a cast fragment of ammonite *Hoplitoplacenticeras* sp., and rostra of belemnites *Belemnitella mucronata mucronata* (Schloth.) and *B. mucronata senior* Now. The transition to overlying sediments is gradual. The thickness is 0.8 m.

(12) Interval 0–1.1 m. Light gray, irregularly silicified bioturbated flaggy marls showing angular fracture and alternating with whitish, slightly glauconitic flaggy calcareous clays locally grading into highly clayey marls. Marls yield abundant and diverse macrofossils: shells of ammonites *Baculites anceps* Lam., *Hopliplacenticeras coesfeldiense coefeldiense* (Schlüt.), *H. coesfeldiense* cf. *costulosum* (Schlüt.), *H. coesfeldiense* cf. *schlueteri* Mikh., *H.* cf. *vari* (Schlüt.), *Trachyscaphites gibbus* (Schlüt.), and *Hoploscaphites roemeri* (d'Orb. non Schlüt.); nautilids *Eutrephoceras* sp.; rostra of belemnites *Belemnitella mucronata senior* Now.; shells of diverse inoceramids *Cataceramus barabini* (Mort.), *C. buguntaensis* (Dobr. et. Pavl.), *C. balticus* (Böhm.), *C. convexus* (Hall et Meek), *C. decipiens* (Zitt.), *C. dariensis* (Dobr. et. Pavl.), *C. regularis* (d'Orb.), and *C. wegneri* (Böhm.); pectinids *Syncyclonema splendens* (Lah.) and *Microchlamys pulchella* (Nills.); oyster species *Monticulina vesicularis* (Lam.), *Acutostrea curvirostris* (Nills.), and *Gryphaeostrea lateralis* (Nills.); gastropods *Callistoma marie* (Muller and *Turritella* sp.; echinoids *Micraster* sp. and *Echinocorys* sp.; sponges *Rhizopoterion* sp. and *Ortodiscus* sp. The apparent thickness is 1.1 m.

MINERAL COMPOSITION AND BIOCLASTS

Macerated foraminiferal and radiolarian residues were used to examine the mineral composition of rocks and bioclasts. Small skeletal remains of organisms and fragments of their larger skeletons are considered here as bioclasts. The occurrence frequency of various components in residues is estimated in conditional categories as "scarce," "rare," "few," "frequent," and "abundant." Being largely subjective, the categories defined by one researcher elucidate additional correlation levels undetectable during study of fossil assemblages.

In total, 14 mineral and organic components are established in the studied residues. Figure 4 demonstrates their distribution throughout the section under consideration.

The Mozhzhevelovyi Ovrag Formation

A single residue from Bed 1 (Sample 24) contains abundant fine-grained quartz and nodular glauconite grains, white mica (muscovite), and bioclasts representing abundant fish remains, scarce radiolarians, and rare spicules of siliceous sponges.

Sandstones of Bed 2 (samples 23 and 22) showed presence of fine-grained, poorly rounded quartz grains abundant in the lower and rare in the upper part. Another mineral component is glauconite colored dark green and nodular. Siliceous sponge spicules and well-rounded fish bone remains are scattered through the entire bed being accompanied by rare radiolarians and scarce phosphatic fecal pellets.

Siliceous marls of Bed 3 (samples 1–3, 1/1–1/4) contain abundant fine-grained angular quartz graons and glauconite, coarse-grained nodular in the lower and fine-grained rounded in the upper part. The lower part of the bed is enriched in flakes of white and greenish mica, which become scarce upward. The basal portion encloses small phosphate nodules (microphosphorite) up to 1.5 mm across. Permanently occurring fish remains and siliceous sponge spicules, frequent and diverse radiolarians, secretory and agglutinated benthic foraminifers represent organic components. Rare fragments of bivalve shells are confined to the bed upper part, while rare prisms of inoceramid shells occur throughout the bed.

Calcareous–siliceous clays of Bed 4 (Sample 4) bear light-green glauconite grains, usually small-sized detrital and less commonly large nodular, and fine poorly rounded quartz and rare phosphate grains. The coarse-grained fraction (>50 μm) constitutes only 1% of the rock. Abundant are flakes of white mica. Secretory foraminifers are rare and poorly preserved. Beginning from this level, radiolarians become abundant in the section. They are accompanied by abundant fish remains, few spicules of siliceous sponges, rare clasts of molluscan shells, inoceram prisms, and scarce fecal pellets and shark teeth.

Bed 5 (Sample 5) marks a sharp decrease in proportion of terrigenous fine-grained quartz, glauconite, and mica (all few); abundance of coarse-grained fraction is negligible (0.2%). It is noteworthy that a single grain of black phosphorite 1 mm across was found precisely at this level. Among organic remains, there are rare tests of benthic foraminifers, abundant fish clasts, radiolarians, rare spicules of siliceous sponges, scarce echinoid needles, and inoceramid prisms.

Lithology of Bed 6 is similar to that of Bed 5: it is also impoverished in coarse terrigenous material and bioclasts (0.4%). The mineral fraction consists of few fine-grained quartz, mica, glauconite, and rare small brown phosphate grains (up to 1 mm across). Sediment contains frequent radiolarians, siliceous sponge spicules, fish remains, rather numerous benthic foraminifers, and rare inoceramid prisms. Based on their composition, sediments of beds 5 and 6 could be united into a single unit.

The Mezino-Lapshinovka Formation

The glauconitic sandstones of Bed 7 (Sample 7) contain abundant light green nodular and rod-shaped glauconite and rare angular fine-grained quartz grains. Organic components are represented by abundant short inoceramid prisms, few fish remains, rare fragments of bivalve shells, rare radiolarians, and scarce foraminifers. Noteworthy is the appearance of small planktonic foraminifers at this level.

The lower portion of Bed 8 of opoka and siliceous clay (samples 8–13 and 25–28) contains nodular and detrital glauconite, proportion of which gradually decreases upward. Sample 11 is barren of glauconite, which appears again higher in the section. In the uppermost part of the bed, glauconite is abundant (17% in Sample 13). The bed is marked by almost complete disappearance of mica and low content of fine-grained quartz. Sediments of the bed accumulated during the transgression peak at maximal distance from provenance. Organic components are represented by rare fish remains (mainly in the lower and partly in the upper part of the bed), rare radiolarians occurring discretely, abundant inoceramid prisms, and shell fragments of other bivalves. Being siliceous in composition and resistant to disintegration, Sample 10 is impoverished in bioclasts. Rare small-sized foraminifers are represented mainly by benthic forms. Planktonic species are registered only at some levels (samples 9 and 12). Rare echinoid needles occur in the upper part of the bed (samples 11–13). Sample 28 (1.5 m below the bed roof) contains rather abungant well-preserved ostracods.

The Rybushka Formation

Data on residue from Bed 9 composed of glauconitic sandstones are somewhat ambiguous. Samples 14 and 32 characterize in fact the hardground crowning Bed 8, which is developed after opokas with deep fucoids. Therefore, both samples consist fifty–fifty of two components: greenish gray to beige–gray siliceous–marly matrix and green glauconite sand filling in fucoids. Since it was impossible to separate these components in the course of sample preparation, the composition of detrital fraction in Bed 9 could be characterized based on samples 15, 29, and 30 collected from higher layers. They contain abundant coarse-grained dark green nodular glauconite and a little of fine-grained quartz. Bioclastic fraction includes rare siliceous sponge spicules, inoceramid prisms, and few rounded bone fragments and scale of fishes. Foraminifers, planktonic forms included, are rare.

Siliceous sandstones of Bed 10 are resistant to disintegration. They bear abundant nodular glauconite, rare fine-grained quartz, tests of benthic foraminifers, and fragments of bivalve shells.

The Ardym Formation

Residues from Beds 11 and 12 (samples 17–21) are similar in composition of mineral and biogenic components. The lower samples 17–19 bear abundant coarse-grained nodular glauconite, while scarce mica flakes occur in Sample 18 only. Fine-grained quartz is rare (Sample 18). Characteristic of Bed 11 are frequent, relatively diverse ostracods, particularly abundant in Sample 18, small Cyrrepedia plates, and rare echinoid needles. Both beds contain relatively abundant, mainly benthic and rare planktonic foraminifers. There are also permanently occurring inoceramid prisms and occasional sponge spicules. We failed to disintegrate opokas of Sample 21, and its component composition remains unknown.

BIOSTRATIRAPHIC ANALYSIS

Mollusks

As is seen from above characteristics of the section, bivalve mollusks are dominated by species *Oxytoma tenuicostata* (Roem.), which is abundant in the Mozhzhevelovyi Ovrag and Mezino-Lapshinovka formations and in the lower part of the Rybushka Formation (beds 1, 3, 4, 6, 8, and 9, Fig. 4). First appearance of *Oxytoma intermedia* A. Ivanov is recorded in the latter unit (Bed 9). In the terminal part of the section (Bed 10), the last species occurs in association with *Oxytoma psilomonica* A. Ivanov, whereas *O. tenuicostata* (Roem.) has not been found at this level. The oyster species *Liostrea wegmaniana* (d'Orb.) is registered in beds 3–8 of the Mozhzhevelovyi Ovrag and Mezino-Lapshinovka formations, while *Acutostrea acutirostris* (Nills.) occurs only in the Mezino-Lapshinovka Formation (beds 7 and 8). Bed 8 yields *Monticulina hippopodia* (Nills.) that is replaced by *Monticulina vesicularis* (Lam.) in the upper part of the Rybushka Formation (Bed 10) and in the Ardym Formation. Finally, *Gryphaeostrea lateralis* (Nills.) occurs sporadically beginning from Bed 5 and then higher in beds 9, 10, and 12.

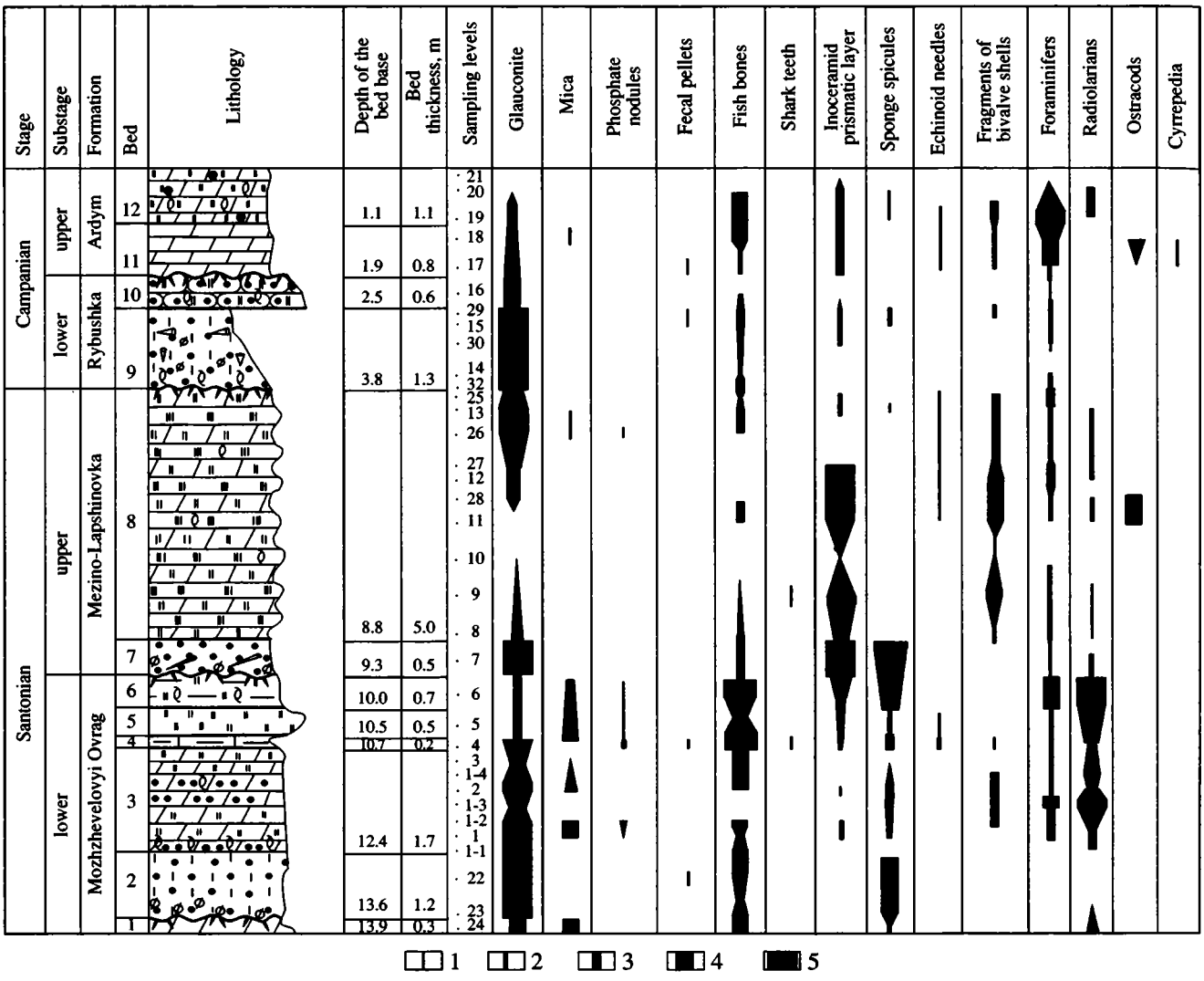


Fig. 4. Distribution of mineral and organic components in the Mezino-Lapshinovka section. The component content in residue: (1) scarce, (2) (rare), (3) few, (4) common, (5) abundant (other symbols as in Fig. 2).

Important among inoceramid forms found in Bed 8 of the Mezino-Lapshinovka Formation is species *Sphenoceramus* cf. *pinniformis* (Willet) characteristic, according to Tröger (2000), of the terminal middle (Zone 27) and basal upper (Zone 28) Santonian in northwestern Germany. It was found in association with *Phenocermus patootensis* Lor., the typical upper Santonian species of West Europe.

The diverse inoceramid assemblage of the Ardym Formation (Bed 12) includes *Cataceramus balticus* (Böhm.), *C. barabini* (Mort.), *C. buguntaensis* (Dobr. et. Pavl.), *C. convexus* (Hall et Meek), *C. dariensis* (Dobr. et Pavl.,), *C. decipiens* (Zitt.), *C. regularis* (d'Orb.), and *C. wegneri* (Böhm.). All the listed species occur in the Campanian and lower Maastrichtian, being most abundant in the upper Campanian. Simultaneously, *Cataceramus dariensis* (Dobr. et Pavl.) was known until recently only from lower Campanian sediments of the Donbas region and northern Caucasus (Kotsyubinskii and Savchinskaya, 1974). Pectinids *Subcyclonema splendens* (Lah.) and *Microchlamys pulchella* (Nills.) from the same bed are most characteristic of the terminal upper Campanian (*Belemnitella langei* Zone) and Maastrichtian in the Russian platform (Kotsyubinskii and Savchinskaya, 1974).

Of greatest interest are cephalopods found in the Ardym Formation (Bed 12) of the Mezino-Lapshinovka section. The ammonite assemblage from this bed includes *Hopliplacenticeras coesfeldiense coesfeldiense* (Schlüt.), *H. coesfeldiense* cf. *costulosum* (Schlüt.), *H. coesfeldiense* cf. *schlueteri* Mikh., *H.* cf. *vari* (Schlüt.), and *Trachyscaphites gibbus* (Schlüt.). Host sediments of these taxa are directly correlative with the upper Campanian *Hoplitoplacenticeras marroti* Zone of the standard scale. These sediments yielded also an ammonite form determined as *Hoplos-*

caphites roemeri (sensu d'Orbigny, 1850, non Schlütter, 1872), because it is barren of tubercles at the lateral side of whorls. Mikhailov (1951, pp. 19 and 98), who determined this form as *Acanthoscaphites* cf. *roemeri* (d.Orb.), reported on its association with various *Hopliplacenticeras coesfeldiense* (Schlüt.) subspecies in cement marls of the Amvrosievka site in southern periphery of the Donbas region.

Belemnites occur in both the Mezino-Lapshinovka (beds 7 and 8) and Rybushka (beds 9 and 10) formations. Sands of Bed 2 yield *Actinocamax verus fragilis* Arkh., *Paractinocamax grossouvrei depressus* (Andreae), and *Belemnitella praecursor* Stoll. The first species is of a relatively wide stratigraphic range (Coniacian–Santonian), while the second one is characteristic of the upper Santonian in southern Sweden, western Germany, and England, and of the *Pteria* Beds in the Kazanskaya Village outskirts, the Don River basin (Naidin, 1964). The third taxon appears in the upper Santonian and occurs in the lower Campanian. *Belemnitella praecursor* Stoll. and *Paractinocamax* ex gr. *grossouvrei* (Janet) were found in the upper Santonian (*Placenticeras paraplanum* Subzone) of French Pyrenees (Cristensen *et al.*, 1993). Marls and opokas of Bed 8 contain *Actinocamax verus fragilis* Arkh. and undeterminable rostra of other belemnites.

A sharp change in composition of belemnite assemblages is established at the boundary between beds 8 and 9. Lower sands of the Rybushka Formation (Bed 9), which yield abundant rostra of *Belemnellocamax mammillatus mammillatus* (Nills.) and *B. mammillatus volgensis* Najd., can be attributed to the terminal part of the lower Campanian (Naidin *et al.*, 1986; Olfer'ev and Alekseev, 2003). In Bed 10, these species are accompanied by *Belemnitella mucronata mucronata* (Schloth.) and *B. mucronata senior* Now., which are found in the overlying Ardym Formation as well (beds 11 and 12). The latter contains also shells of gastropod taxon *Calliostoma* cf. *mariae* (Müller), which is typical of the *Mucronata* Chalk in Germany (Blank, 1974).

Foraminifers

The lowermost foraminiferal assemblage is established in Sample 1 from Bed 3 of the Mozhzhevelovyi Ovrag Formation (Fig. 5). It includes the following taxa: ataxophragmiids *Harena amanda* (Wolosch.) and *Novatrix obesa* (Reuss); nodosariids, in particular stratigraphically important neoflabellins with prevalent *Neoflabellina* cf. *gibbera* (Wedek.), *N.* cf. *santonica* Koch. and occasional *N.* cf. *suturalis* (Cushm.); discorbids *Valvulineria mariei* Vass., *Stensioeina exculpta exculpta* (Reuss), *S. granulata* cf. *perfecta* Koch, and *S. mursataiensis* Vass., which represents probably a senior synonym of the West European subspecies *Stensioeina granulata incondita* Koch; anomalinids *Cibicides beaumontianus* (d'Orb.); buliminids *Praebulimina ventricosa* (Brotz.). Almost identical assemblage occurs slightly higher, in Sample 1/2. Forms supplementing the assemblage in the higher Bed 3 (Sample 2) are *Osangularia whitei* (Brotz.), *O. corderiana* (d'Orb.), *Gyroidinoides girardanus* (Reuss), *Stensioeina granulata granulata* Koch, and abundant *S. mursataiensis* Vass. Bed 4 (Sample 4) yields an impoverished assemblage consisting of *Harena amanda* (Wolosch.), *Novatrix obesa* (Reuss), *Praebulimina ventricosa* (Brotz.), and of a test fragment probably belonging to *Neoflabellina* cf. *deltoidea* Wedek. The single species *Novatrix obesa* (Reuss) is present in Bed 5. *Stensioeina mursataiensis* Vass., *S. granulata* cf. *perfecta* Koch, *Neoflabellina* cf. *gibbera* (Wedek.), *N.* cf. *santonica* Koch, *N.* cf. *suturalis* (Cushm.), *N.* cf. *deltoidea* (Wedek.), and *Valvulineria mariei* Vass. represent the assemblage from beds 3–5 of the Mozhzhevelovyi Ovrag Formation, which are correlative with the lower Santonian *Stensioeina granulata perfecta* Zone of western Kazakhstan or with the terminal part of the *Gavelinella infrasantonica* Zone of the East European platform (Akimets *et al.*, 1991). In West Europe, this zone spans the middle–upper Santonian boundary layers (Koch, 1977; Bailey *et al.*, 1984; Schönfeld, 1990), as the three-member subdivision of the stage is accepted here.

The assemblage from Bed 6 (Sample 6) is similar to that from underlying sediments of the Mozhzhevelovyi Ovrag Formation and also includes *Harena amanda* (Wolosch.), *Novatrix obesa* (Reuss), *N.* cf. *santonica* Koch, *Stensioeina exculpta exculpta* (Reuss), *S. granulata* cf. *perfecta* Koch, *S. mursataiensis* Vass., and *Praebulimina ventricosa* (Brotz.). Noteworthy is the first appearance of single small-sized *Gavelinella stelligera* (Marie) at this level. This taxon is an index species of the synonymous local zone corresponding to the Santonian in the regional Upper Cretaceous scheme of the East European platform (Olfer'ev and Alekseev, 2003).

The next assemblage characterizes the Mezino-Lapshinovka Formation. Appearing in the lower part of this formation (samples 9 and 11) are *Stensioeina* cf. *pommerana* Brotz., abundant typical *Gavelinella stelligera* (Marie) and *Eponides?* aff. *grodnoensis* Akim. The last form is very close to *Eponides moskvini* (Kell.). These species are accompanied by *Valvulineria mariei* Vass. and *Praebulimina ventricosa* Brotz. characteristic also of the Mozhzhevelovyi Ovrag Formation. In the terminal part of the Mezino-Lapshinovka Formation (samples 28, 12, 26, 13), the assemblage shows a decreased abundance of neoflabellins, newcomers among which are abundant typical *Neoflabellina deltoidea* (Wedek.) and *N. suturalis* (Cushm.) from samples 28 and 13. Additional renewals in the assemblage are recorded at the appearance levels of *Quadrimorphina minuta* (Cushm.) and of *Gavelinella dainae* (Mjatl.) in samples 26 and 13 respectively. Planktonic forms *Whiteinella* sp., *Archaeoglobigerina* sp., *Globotruncana globigerinoides* (Marie), *Rugoglobigerina rugosa* (Plumm.), and *Helvetiella* sp. also appear at these levels.

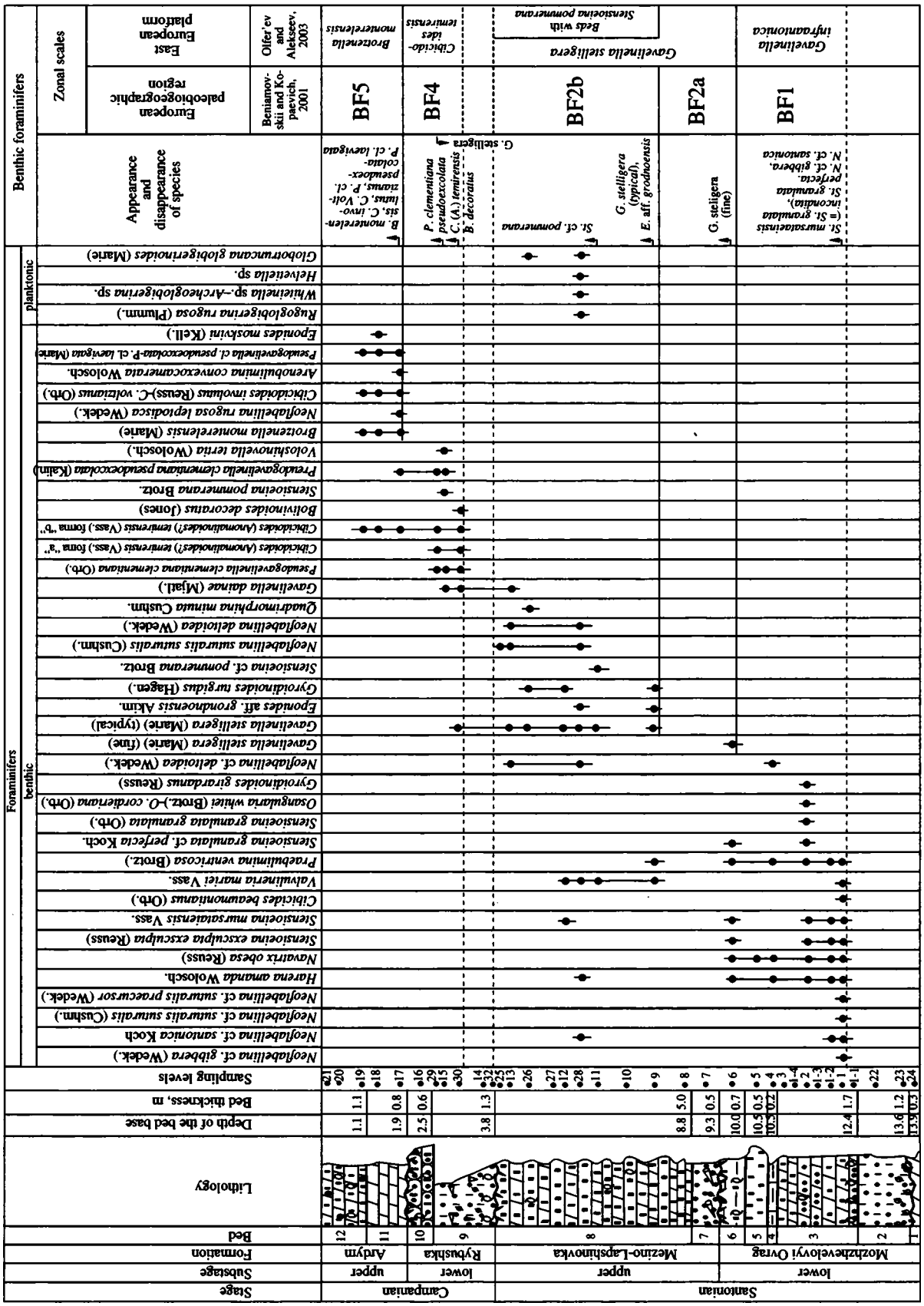


Fig. 5. Distribution of foraminifers in the Mezino-Lapshinovka section (legend as in Fig. 2).

The Mezino-Lapshinovka foraminiferal assemblage corresponds to that from the terminal part of the upper Santonian *Gavelinella stelligera* Zone in the East European platform defined by Olfer'ev and Alekseev (2003) in the rank of the *Stensioeina pommerana* Beds. According to Schönfeld (1990), in northwestern Germany the zonal species *Stensioeina pommerana* (Brotz.) appears in the uppermost Santonian *Stensioeina pommerana/Gaudryina frankei* Zone. Beds with *Stensioeina pommerana* are correlative with the *Stensioeina pommerana* Subzone (BF2b) in the detailed upper Santonian–Maastrichtian zonal scale of the European paleobiogeographic region (Beniamovskii and Kopaevich, 1998, 2001), which represents a synthesis of two scales elaborated for the eastern part of the European paleobiogeographic region (Naidin *et al.*, 1984a, 1984b) and northwestern Germany (Koch, 1977; Schönfeld, 1990). Recently, the detailed correlation between these scales showed that the lower boundary of the *Stensioeina pommerana* Subzone (BF2b) in the synthesized scheme is placed incorrectly. In fact, it should be drawn inside the Santonian, since, as was mentioned, the first appearance of *Stensioeina pommerana* (Brotz.) is recorded in the terminal Santonian (Schönfeld, 1990).

It should be emphasized that the foraminiferal assemblage from the Mezino-Lapshinovka Formation is identical to that from *Pteria* Beds of the Ul'yanovsk region near the Volga River, where the beds are marked by the first appearance of *Eponides* aff. *grodnoensis* Akim., *Stensioeina pommerana* Brotz., *Gavelinella stelligera* (Marie), and *G. dainae* (Mjatl.) (Beniamovskii *et al.*, 1988, p. 68).

The foraminiferal assemblage of the Rybushka Formation is established in Bed 9 (samples 30, 15, and 29). *Gavelinella stelligera* (Marie) and *G. dainae* (Mjatl.) known from the Mezino-Lapshinovka Formation remain abundant in the bed. Except for these species, the composition of the assemblage is different. *Pseudogavelinella clementiana clementiana* (d'Orb.), *Bolivinoides decoratus* (Jones), and *Cibicidoides (Anomalinoides?) temirensis* (Vass.) appear in Sample 30. The last taxon is represented by morphotypes "a" and "b." The first of them has a symmetrically biconvex test and symmetrical oval–triangular septal surface. The second morphotype demonstrates features reflecting the initial stage of transition to *Cibicidoides inolatus* (Reuss) [=*C. aktulagayensis* (Vass.)]. It is characterized by a flatter spiral side and more distinct outlines of the septal surface with tendency for its incline toward the umbonal area.

Index species *Cibicidoides (Anomalinoides?) temirensis* (Vass.) and *Bolivinoides decoratus* (Jones) present in the assemblage suggest correlation of host deposits with the *Cibicidoides temirensis* Zone of the East European platform (Olfere'ev and Alekseev, 2003) or the *Bolivinoides decoratus decoratus* Zone (BF4) of the European paleobiogeographic region (Beniamovskii and Kopaevich, 2001). The assemblage from overlying sediments (Sample 15) additionally uncludes *Voloschinovella tertia* (Wolosch.), *Pseudogavelinella clementiana pseudoexcolata* (Kalin.), typical *Stensioeina pommerana* (Brotz.), and planktonic forms of the *Heterohelix*, *Rugoglobigerina*, and *Globotruncana* genera.

The assemblage contained in uppermost Sample 29 from the Rybushka Formation is different in two features from the lower assemblage of that formation: first, *Gavelinella stelligera* (Marie) and *G. dainae* (Mjatl.) disappear and, second, occasional tests of *Brotzenella monterelensis* (Marie), an index species of the younger zone, appears at this level. In our opinion, appearance of the latter is a result of contamination from overlying Ardym sediments filling in crustacean burrows.

The compositional peculiarities of foraminiferal assemblage from the Rybushka Formation, which substantially less thick in the studied section than in stratotype (Ivanov, 1995, pp. 64–65), indicate that host deposits are likely correlative with the *Cibicidoides aktulagayensis* Subzone of the East European platform or with the BF4c Subzone of the European paleobiogeographic region (Beniamovskii and Kopaevich, 2001).

We failed to extract foraminifers from sandstones of Rybushka Formation (Bed 10), because they are strongly silicified.

The foraminiferal assemblage from the Ardym Formation is macerated from beds 11 and 12 (samples 17–19). It is marked by appearance of *Arenobulimina convexocamerata* Wolosch., *Neoflabellina rugusa leptodisca* (Wedek.), *Brotzenella monterelensis* (Marie), *Eponides moskvini* (Kell.), and *Cibicidoides involutus* (Reuss) in Sample 18. Tests of the last species occurring together with *Cibicidoides (Anomalinoides?) temirensis* (Vass.) forma "b" slightly differ from typical representatives of this taxon. In some features, it is close to *C. voltzianus* (d'Orb.), the evolutionary descendant of *C. involutus* (Reuss). Forms transitional to *Pseudogavelinella clementiana laevigata* (Marie) with reduced ornamentation on the spiral side occur among abundant *Pseudogavelinella clementiana pseudoexcolata* (Kalin.).

In its composition, the assemblage in question is comparable with that of the *Brotzenenella monterelensis* local zone of the regional East European scale (Olfer'ev and Alekseev, 2003) or BF5 Zone of the European paleobiogeographic region (Beniamovskii and Kopaevich, 2001).

Forms present in the assemblage, which are transitional between *C. involutus* (Reuss) [=*C. aktulagayensis* (Vass.)] and *C. voltzianus* (d'Orb.), imply that the Ardym Formation of the studied section is correlative with the upper part of the *Brotzenenella monterelensis* Zone.

Radiolarians

Three radiolarian assemblages are distinguished in the examined section (Fig. 6).

The most representative lower assemblage of diverse and abundant radiolarians is confined to beds 1–5 of the Mozhzhevelovyi Ovrag Formation. It includes *Alievium superbum* (Squin.), *A. praegallowayi* Pess., *Archaespongoprunum bipartitum* Pess., *A. triplum* (Pess.), *Pseudoaulophacus venadoensis* Pess., *P. praefloresensis* Pess., *Orbiculiforma persenex* Pess., *Cavaspongia euganea* (Squin.), *Crucella cachensis* Pess., *Pyramispongia glascockensis* Pess., *P. costarricensis* (Schmidt-Effing), *Praeconocaryomma lipmanae* Pess., *Dictyomitra napaensis* Pess., and several new species. In the Californian sections, Pessagno (1976) defined the Turonian *Alievium superbum* Zone of the Pacific province, admitting simultaneously that this species may occur in the lower Coniacian as well. Subsequently, the indicated index species was found in the Turonian–Coniacian of the Pacific (Schaaf, 1986) and in the lower Coniacian Chernetovka Formation exposed in the Sobolevskoe quarry of the Kaluga region (data of Olfer'ev and Vishnevskaya). *A. praegallowayi* occurring in the assemblage was proposed by E. Pessagno as an index species for the synonymous zone corresponding to the entire Coniacian Stage, although he also supposed the species presence in the basal Santonian. It is important that epibole of *Archaespongoprunum bipartitum* is characteristic, according to Pessagno, of the lower subzone of the *Alievium praegallowayi* Zone. In addition, almost all the above-mentioned species of the assemblage, except for *Alievium superbum* (Squin.), *Dictyomitra napaensis* Pess., and *Pyramispongia* forms, are known from the middle Coniacian–lower Santonian Zagorsk Formation of the Moscow syneclise (Olfer'ev *et al.*, 2000). Based on the integral distribution range of radiolarians from the Mozhzhevelovyi Ovrag Formation, the assemblage can be dated back to the Turonian–Coniacian.

The second assemblage with *Pseudoaulophacus floresensis* is established in Bed 6 crowning the Mozhzhevelovyi Ovrag Formation (Sample 6) and also in Sample 12 from Bed 8 of the Mezino-Lapshinovka Formation. Present in this assemblage are *Pseudoaulophacus floresensis* Pess., *Prunobrachium sibiricum* (Lipm.), *Rhopalastrum attenuatum* Lipm., *R. tumidum* Lipm., *Crucella espartoensis* Pess., *Dictyomitra densicostata* Pess., and some other forms. All the species, except for the last one appearing in the upper part of the Coniacian, range from the Santonian to the Campanian, thus implying the Santonian–early Campanian age of host beds. Nevertheless, *Crucella chachensis* Pess., *Histiastrum latum* Lipm., *Euchitonia santonica* Lipm., *Orbiculiforma quadrata* Pess., and *Dictyomitra striata* Lipm., which disappear at the Santonian–Campanian boundary, point likely to the Santonian age of beds enclosing the *Pseudoaulophacus floresensis* assemblage.

The third radiolarian assemblage is defined in Bed 12 (samples 19 and 20) of the Ardym Formation. It consists of rare specimens belonging to five species, most of which are known from the older assemblage. Four of them are *Rhopalastrum attenuatum* Lippm., *Porodiscus* cf. *vulgaris* Lipm., *Xitus asymbatos* (Forem.), *Dictyomitra densicostata* Pess. The fifth form of the assemblage (*Orbiculiforma minticelloensis* Pess.) appears precisely at this level. The assemblage is the Campanian in age.

Calcareous nannoplankton

Sufficiently abundant calcareous nannofossils moderately or well preservd occur virtually throughout the section beginning from Bed 2 of the Mozhzhevelovyi Ovrag Formation (Fig. 7). The bed contains an extremely impoverished assemblage that includes *Micula staurophora* (Gard.) Stradn., *M. concava* (Stradn.) Verb., *Eiffellithus eximius* (Stov.) Perch-Niels., *Kamptnerius magnificus* Defl., and *Marthasterites furcatus* (Defl.) Defl. The first four species occur throughout the entire section, whereas the last one disappears at the base of the Rybushka Formation at the level of Sample 15. Based on the presence of *Micula staurophora* (Gard.) Stradn., the assemblage can be correlated with the Zone CC14 (Perch-Nielsen, 1985; Wagreich, 1992; Burnett, 1998). In this sample, like almost in all the samples from overlying sediments, the last species is associated with *Micula concava* (Stradn.) Verb., the appearance of which marks the lower boundary of the younger Zone CC15 (Perch-Nielsen, 1985). It should be noted also that Melinte (1999) assumes the appearance of this species in the terminal part of the Zone CC14 of Romania.

Beginning from Bed 3 of the Mozhzhevelovyi Ovrag Formation, the nannoplankton assemblage becomes more diverse, consisting of over 20 species (Fig. 7). Among them, worthy of mentioning is *Prediscosphaera grandis* Perch-Nielsen. Burnett (1998) correlated the appearance level of this species and *Micula concava* (Stradn.) Verb. with the base of the *Texanites texanus* ammonite zone that begins the Santonian Stage in the Upper Cretaceous scale of the East European platform (Olfer'ev and Alekseev, 2002). In opinion of Burnett, the same biotic event took place in the Boreal realm at the middle of Subzone UC11 and approximately corresponds to the base of the Santonian Stage.

In overlying beds 4 and 5 of the same formation, the nannoplankton assemblage is almost unchanged, incorporating additionally only three species of a wide stratigraphic range. Its composition becomes more diverse in the terminal part of the Mozhzhevelovyi Ovrag Formation (Bed 6; Fig. 7), although new forms appearing here are inappropriate for age determination.

A more substantial renewal of nannoplankton is recorded in the Mezino-Lapshinovka Formation, where its diverse assemblage includes 40 species. Basal sands of the formation (Bed 7) recorded first appearance of

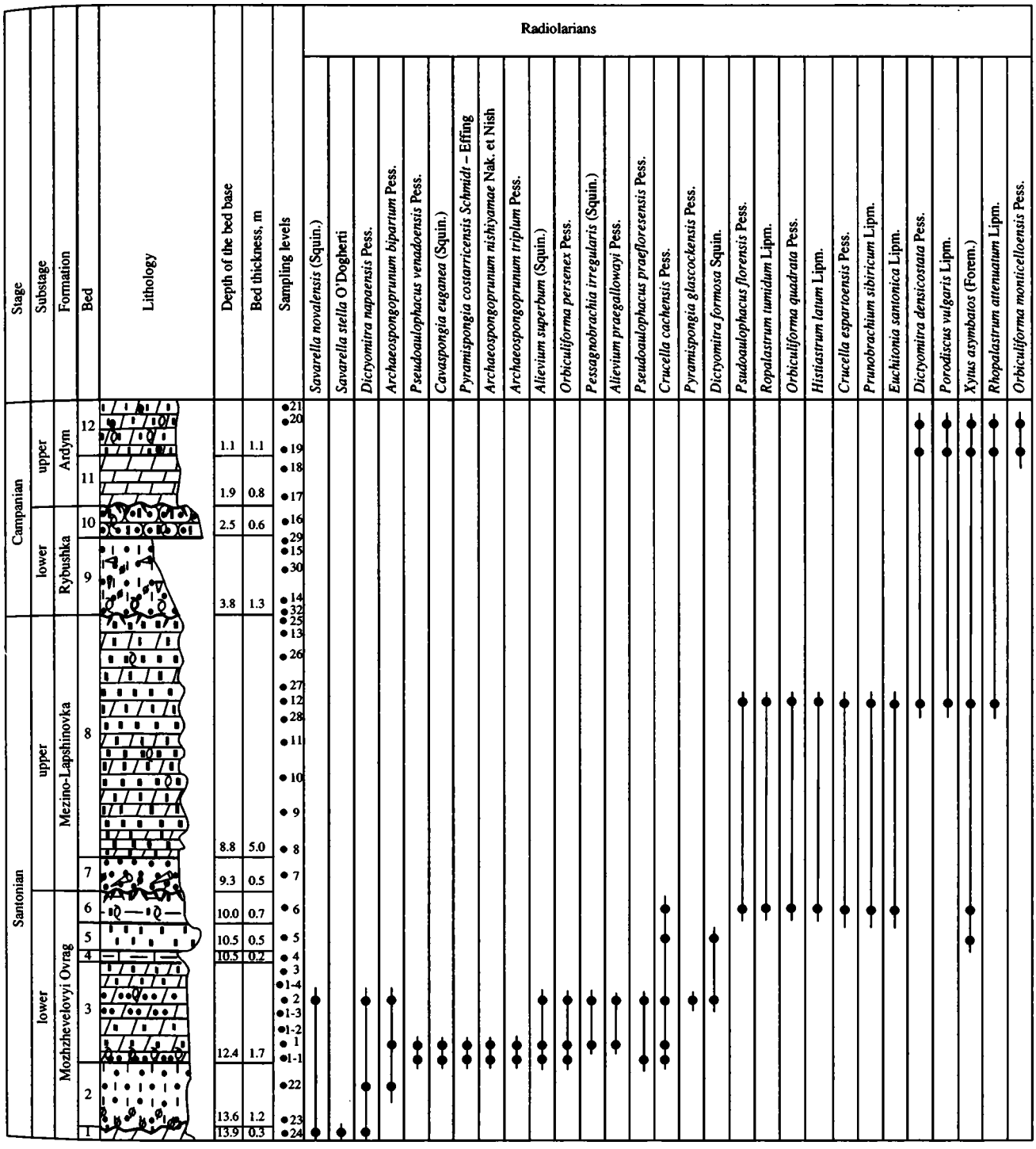


Fig. 6. Distribution of radiolarians in the Mezino-Lapshinovka section (legend as in Fig. 2).

Reinhardtites anthophorus (Defl.) Perch-Niels., and this event corresponds to the base of the synonymous Zone CC15 (Sissingh, 1977; Perch-Nielsen, 1985). This newcomer is a permanent component of assemblages higher in the section.

It is important that *Lithastrinus grillii* Stradn. appears first in Bed 8, (Sample 13), because this taxon marks, according to Burnett (1998), the base of the Coniacian–lower Santonian Zone UC11. Simultaneously, species *Zeugarhabdotus diplogrammus* (Defl.) Gartn. present in samples 10 and 12 but absent in Sample 13, suggests, as it follows from the scheme by Burnett, that the interval in question is not older than the late Santonian (*Unitacrinus socialis* Zone).

The next notable change in composition of nannoplankton is recorded at the base of the Rybushka Formation (Fig. 7). A significant event detected at this level, i.e., the appearance of *Broinsonia parca parca* (Stradn.) Bukry, marks, according to many observations, the base of the Campanian Stage. Precisely, the appearance level of this form characterizes zones NC18 (Roth, 1978), CC18 (Perch-Nielsen, 1985), and UC14 (Burnett, 1998). At the same time, *Marthasterites furcatus* (Defl.) Defl., which should disappear at the base of the Zone CC19 (Sissingh, 1977; Wise, 1983; Doeven, 1983; Perch-Nielsen, 1985), is missing at this level. Sandstones of Bed 10 crowning the Rybushka Formation yield *Broinsonia parca constricta* Hattn. et al., the taxon marking the lower boundary of subzones CC18b (Perch-Nielsen, 1985) and UC14b (Burnett, 1998).

The nannoplankton assemblage from the Ardym Formation (Bed 11) is characterized by the appearance of *Arkhangelskiella cymbiformis* Veksh., which was used by different researchers as the zonal index species. For instance, Sissingh (1977) correlated its first appearance with the base of the upper Maastrichtian Zone CC25. Perch-Nielsen (1985) proposed to use this species as an alternative marker for the base of the upper Campanian Zone CC21 in high latitudes. Burnett (1998) used the appearance of *A. cymbiformis* Veksh. to define the Zone UC13 at the base of the lower Campanian. These controversial opinions concerning the taxon stratigraphic range are explainable by the different understanding of its scope (Perch-Nielsen, 1985). In addition to forms of wide stratigraphic ranges, forms encountered at the level in question are *Calculites ovalis* (Stradn.) Prins et Siss. and *Ceratolithoides* cf. *aculeus* (Prins et Siss.) Stradn. (Fig. 7). The first species was considered as denoting the base of Zone CC19 in the zonal scale of Perch-Nielsen (1985), although its earlier appearance is established recently (Lamolda *et al.*, 2002; observations of Shcherbinina). The second form is known beginning from the Zone CC20 (Perch-Nielsen, 1985) or Subzone UC15b of the Boreal realm (Burnett, 1998).

The calcareous nannoplankton assemblage from Bed 12 of the Ardym Formation crowning the Mezino-Lapshinovka section includes first *Ceratolithoides verbeckii* Perch-Niel., *Prediscosphaera stoveri* (Perch-Niels.) Shaf. et Stradn., and *Lucianorhabdus arcuatus* Forchh. The first of these species marks the base of the Subzone CC18c (Perch-Nielsen, 1985) or Subzone UC14d in the Tethyan realm (Burnett, 1998) and the second form appears in the Subzone UC15d of the Boreal realm and transitional areas from this to the Tethyan realm.

AGES OF FORMATIONS

Ages of formations exposed in the Mezino-Lapshinovka quarry are estimated based on enclosed paleontological remains, and their stratigraphic positions in the Upper Cretaceous succession of the Russian plate are given in accordance with the regional stratigraphic scheme of the East European platform (Olfer'ev and Alekseev, 2002, 2003). Shortly after the acceptance of this scheme, working groups of the International Subcommission on Cretaceous Stratigraphy proposed stratotypes of lower boundaries for the Santonian (Lamolda *et al.*, 2002) and Maastrichtian (Odin, 2001) stages at substantially lower stratigraphic levels as compared with those traditionally accepted in Russia. In this connection, ages of Upper Cretaceous formations defined in the Volga region can be defined ambiguously depending on the viewpoint of different researchers on relevant boundaries. The problem is partly discussed in further sections of the paper. Nevertheless, to avoid insurmountable difficulties, we accepted ranges of units as they are defined in the standard scale outlined recently by two of us (Olfer'ev and Alekseev, 2002). It should also be kept in mind that Upper Cretaceous nannofossils from the Russian plate are inadequately studied and, accordingly, the reliable age estimates based on nannoplankton from local stratigraphic units are unknown in the plate. Therefore, we defined zonal subdivisions in this work mainly based on succession of species appearances in the type Upper Cretaceous sections of North Europe (Hardenbol *et al.*, 1998).

The Mozhzhevelovyi Ovrag Formation

In the examined section, this stratigraphic unit is represented only by its uppermost layers. In complete sections, it includes cardissoid marls with the sponge horizon at the base, which grade upward into "banded sequence" composed of alternating opokas, siliceous marls, and clays. The cardissoid marls are missing from sections near arches of positive structures. The "banded group" is referred to either the lower (Arkhangel'skii, 1912; Milanovskii, 1940; Glazunova, 1972) or the upper Santonian (Naidin and Morozov, 1986, p. 100).

Layers exposed in the Mezino-Lapshinovka quarry belong to the "banded sequence" that is confirmed by presence of abundant flakes of white mica characteristic of opokas from this part of the sections in the Volga River region (Arkhangel'skii, 1912). The recovered molluscan remains, except for *Oxytoma tenuicostata* (Roem.) and *Liostrea wegmaniana* (d'Orb.), which Glazunova (1972) considered to be the late Santonian in age, are species of wide stratigraphic ranges. In addition, beds 3–6 enclose the assemblage of benthic foraminifers of the *Stensioeina granulata perfecta* Zone (Akimets *et al.*, 1991) or Zone XI of the European paleobiogeographic region (Beniamovskii and Kopaevich, 2001). Both zones correspond to the upper portion of the lower Santonian and to the terminal part of the lower Santonian *Gavelinella infrasantonica* Zone in the regional scale (Olfer'ev and Alekseev, 2003). It should be kept in mind, however, that in northwestern Germany, where the Santonian is divided into three substages (Schönfeld, 1990), the *Stensioeina granulata*

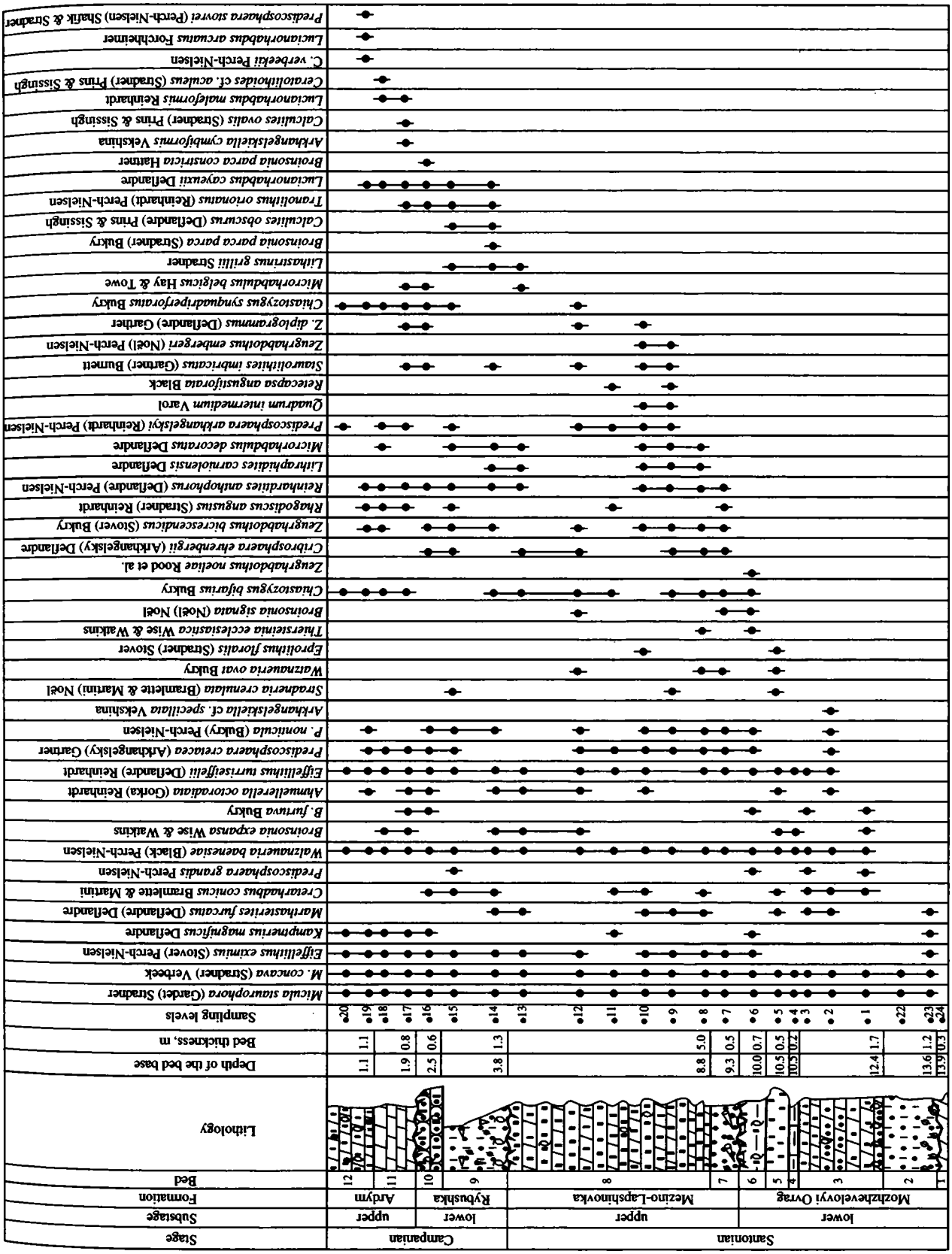


Fig. 7. Distribution of calcareous nannoplankton in the Mezino-Lapshinovka section (legend as in Fig. 2).

perfecta Zone spanning the middle–upper Santonian boundary layers is located above the *Cibicides eriksdlensis–Gavelinella vombensis* Zone. Thus, it should be correlated with the lower part of the upper Santonian Substage in case of the two-member subdivision of the stage. The *Cibicides eriksdalensis–Gavelinella vombensis* Zone can be considered as an equivalent of the *Gavelinella infrasantonica* Zone, because *Gavelinella vombensis* (Brotzen, 1945) is a senior synonym of *Gavelinella infrasantonica* (Balakhmatova, 1954) species (Beniamovskii and Kopaevich, 2001). Scarce small tests of *Gavelinella stelligera* (Marie) present in opokas terminating the Mozhzhevelovyi Ovrag Formation probably indicate transition to the upper Santonian *Gavelinella stelligera* Zone of the regional scale (Olfer'ev and Alekseev, 2003). It should be emphasized that the appearance of first non-typical tests of *Gavelinella* ex gr. *stelligera* in Mangyshlak is confined to the *Uintacrinus socialis* Zone (Naidin *et al.*, 1984b). This zone corresponds to the lower part of the upper Santonian Substage, when the stage is divided into three substages (Hancock and Gale, 1996; Lamolda and Hancock, 1996).

Based on radiolarians, the Mozhzhevelovyi Ovrag Formation is interpreted to be the Turonian–Santonian in age based on Pacific scales by Pessagno (1973, 1975, 1976) and on Tethyan scale by O'Doherty (1994), although all the taxa from the relevant assemblage, zonal species *Alievium superbum* included, either continue to exist or appear first in the Coniacian. Species, the lower distribution limit of which is restricted to the Coniacian, e.g., *Pseudoaulophacus venadoensis* Pess., *Archaeospongoprunum bipartitum* Pess., *A. triplum* Pess., and *A. nishiyanae* Nak. et Nish., likely point to the Coniacian age of the formation layers exposed in the quarry. On the other hand, similarity between the radiolarian assemblage in question and that from the middle Coniacian–lower Santonian Zagorsk Formation of the Moscow syneclise (Olfer'ev *et al.*, 2000) implies the Coniacian–early Santonian radiolarian-based age of the Mozhzhevelovyi Ovrag Formation that is consistent with the transitional, Santonian or Santonian–Campanian affinity of assemblage from the uppermost Sample 6.

According to permanent occurrence of calcareous nannoplankton species *Micula staurophora* (Gard.) Stradn., the Mozhzhevelovyi Ovrag Formation can be correlated with the Zone CC14 corresponding to the Coniacian–lower Santonian in the Tethyian scale (Hardenbol *et al.*, 1998). Presence of *Micula concava* (Stradn.) Verb., the first appearance of which marks the base of the younger Santonian Zone CC15 (Verbeek, 1977; Perch-Nielsen, 1985), implies however that terminal beds of the unit may correspond to the Santonian. It should be emphasized that beginning from Bed 3 sediments permanently contain scarce specimens of *Prediscosphaera grandis* Perch-Niels., the taxon that appears in northern Europe near the Coniacian–Santonian boundary (Burnett, 1988) simultaneously with *Micula concava* (Stradn.) Verb. On the other hand, single specimens of *P. grandis* occur both below and above this level in the Olazagutia section of Spain proposed for the global stratotype of the Santonian lower boundary (Lamolda *et al.*, 2002). In addition, *Micula concava* is established in the upper Coniacian of the Carpathians in Romania (Melinte, 1999).

In general, data on all the organic remains suggest the early Santonian age of the Mozhzhevelovyi Ovrag Formation, although radiolarians from the unit are slightly older.

The Mezino-Lapshinovka Formation

As is shown above, inoceramids and belemnites unambiguously point to the late Santonian age of the Mezino-Lapshinovka Formation in its stratotype. Based on foraminifers, the lower part of Bed 8 can be reliably correlated with the upper Santonian *Gavelinella stelligera* Zone, as it is evident from appearance of typical large representatives of index species along with *Gyroidinoides turgidus* (Hag.) and *Eponides* aff. *grodnoensis* Akim. beginning from Bed 9. The assemblage from the upper part of Bed 8 (Sample 11) includes *Stensioeina* cf. *pommerana* Brotz., *Gavelinella dainae* (Mjatl.), *Quadrimorphina minuta* (Cushm.), and *Neoflabellina deltoidea* (Wedek.), and their host sediments are correlative therefore with the *Stensioina pommerana* Beds (Olfer'ev and Alekseev, 2003). In northwestern Germany, the *Stensioina pommerana–Eponides frankei* Zone corresponds to the upper part of *Marsupites* Beds (*Marsupites testudinarius* Zone) of the terminal Santonian. Thus, based on benthic foraminifers, the Mezino-Lapshinovka Formation should likely be correlated with the entire upper Santonian Substage.

Radiolarian assemblages from both the upper bed of Mozhzhevelovyi Ovrag Formation and the Mezino-Lapshinovka Formation are of the Santonian affinity, although its belonging to the basal part of the lower Santonain cannot be ruled out.

It is difficult to establish age of the Mezino-Lapshinovka Formation based on the calcareous nannofossils. Shcherbinina considers the Zone CC15 marked by the first appearance of *Reinhardtites anthophorus* (Defl.) Perch-Niels. as correlative with the upper Coniacian. In her opinion, this is also consistent with the first appearance of *Lithastrinus grillii* Stradn. near the top of the Mezino-Lapshinovka Formation. Based on the last species, Burnett (1998) defined Zone UC11 that was correlated by Shcherbinina with the Coniacian–Santonian boundary interval. In addition, it should be emphasized that *Thiersteinia ecclesiastica* Wise et Watk. and *Quadrum intermedium* Varol. disappear respectively in the lower and middle parts of the Mezino-Lapshinovka Formation. According to Burnett (1998), the first event is recoreded inside the *Gauthiceras margae* Zone in the Southern realm and the second one in the *Peroniceras*

tridorsatim Zone, i.e., in the middle Coniacian of northern Europe.

The estimated older age of nannoplankton from the Mezino-Lapshinovka Formation is inconsistent with the data on other fossil groups. It can probably be explained by redeposition of nannofossils, which should disappear during the Coniacian, or by locally delayed appearance of younger index taxa, the phenomenon frequently observed in Upper Cretaceous section of high latitudes. In addition, the nannoplankton age younger than Coniacian is evident from several other facts. First, *Reinhardtites anthophorus* (Defl.) Perch-Niels., an index species of the lower Santonian Zone CC15 (Sissingh, 1977, 1978; Perch-Nielsen, 1985) occurs in the formation section beginning from its base. Second, *Zeugrhabdotus diplogrammus* (Defl.) Gartn., which disappears in West Europe in the mid-upper Santonian *Uintacrinus socialis* Zone (Burnett, 1998), is present only in samples 10 and 12. Third, Ovechkina (2002) found *Lucianorhabdus cayeuxii* Defl. in the Mezino-Lapshinovka Formation of the Pudovkino section. This taxon characteristic of the upper Santonian Zone CC16 (Perch-Nielsen, 1085) appears in the Olazagutia section of Spain immediately below the recently proposed Coniacian–Santonian boundary.

The Rybushka Formation

In the examined section, the Rybushka Formation spanning the lower–upper Campanian boundary strata in the stratotype is separated from the Mezino-Lapshinovka Formation by a considerable hiatus. Correspondence of Bed 9 to the terminal lower Campanian is substantiated by presence of belemnites *Belemnellocamax mammillatus mammillatus* (Nilss.) and *B. mammillatus volgensis* (Najd)., and this part of the section can be attributed to the *Belemnellocamax mammillatus* Zone of the regional scale (Olfer'ev and Alekseev, 2003). The same stratigraphic interval is indicated by foraminifers characteristic of the upper part of the *Bolivinoides decoratus decoratus* (BF4) Zone in the scale proposed for the European paleobiogeographic region (Beniamovsklii and Kopaevich, 2001). The appearance of *Broinsonia parca parca* (Stradn.) Bukry among nannofossils also implies that Bed 9 is correlative with the lower Campanian.

In Bed 10, *Belemnellocamax* forms are accompanied by *Belemnitella mucronata mucronata* (Schloth.) and *B. mucronata senior* (Now.), which are of a little significance, because these subspecies occur in both the terminal lower and basal upper Campanian (Naidin, 1964). The appearance of *Broinsonia parca constricta* Hattn. in the nannoplankton assemblage suggests that sandstones of Bed 10 are not older than the lower Campanian Zone CC18 at least. Thus, the Rybushka Formation, which is of the early–late Campanian age considered in the standard Upper Cretaceous stratigraphic scale, in the Mezino-Lapshinovka section is represented by lower Campanian strata only.

The Ardym Formation

Correlation of the Ardym Formation with the lower zone of the upper Campanian is unambiguously confirmed by ammonites *Hopliplacenticeras coesfeldense coesfeldense*, *H. coesfeldense* cf. *costulosum* (Schlüt.), *H.* cf. *vari* (Schlüt.), and *Trachyscaphites gibbus* (Schlüt.) found in the unit. This assemblage is typical of the West European *Hopliplacenticeras marroti* Zone. The late Campanian age of the formation is also consistent with finds of belemnites *Belemnitella mucronata mucronata* (Schloth.) and *B. mucronata senior* (Now.). Inoceramids *Cataceramus balticus* (Böhm.), *C. barabini* (Mort.), *C. buguntaensis* (Dobr. et Pavl.), *C. convexus* (Hall et Meek), *C. decipiens* (Zitt.), *C. regularis* (d'Orb.), and *C. wegneri* (Böhm.) occurring in the Ardym Formation are most characteristic of the upper Campanian, although their stratigraphic range spans the entire Campanian and Maastrichtian as well. The benthic foraminifer assemblage, which is typical of the upper portion of the *Brotzenella monterelensis* Zone, also supports the age estimated above.

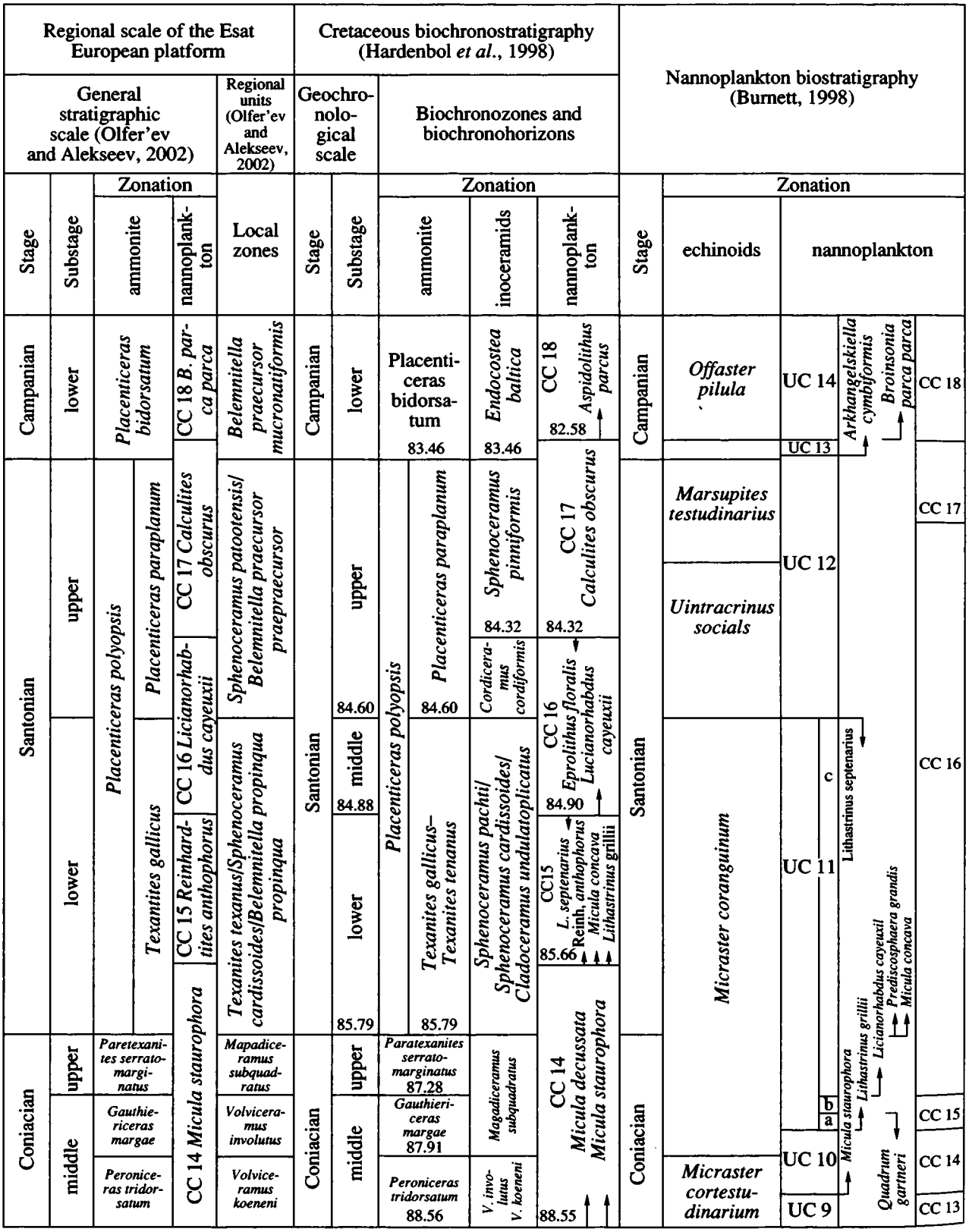
At first sight, the successive appearance of *Broinsonia parca parca* (Stradn.) Bukry (Sample 14), *B. parca constricta* Hattn. *et al.* (Sample 16), and *Ceratholitoides verbeckii* Perch-Nielsen (Sample 19) among calcareous nannoplankton indicates the early Campanian age of host sediments (subzones a, b, and c, respectively). This inference is however inconsistent with appearance of *Calculites ovalis* (Stradn.) Prins et Siss., which is characteristic of the upper Campanian Zone CC19, at the base of the Ardym Formation (Sample 17). The late Campanian age of nannoplankton is also supported by presence of *Prediscosphaera stovei* (Perch-Niels.) Shof. et Stradn. in Sample 19. Burnett (1998) reported on first appearance of this species in the upper Campanian *Caleola basiplana–Trachyscaphites spiniger* Zone of northwestern Germany.

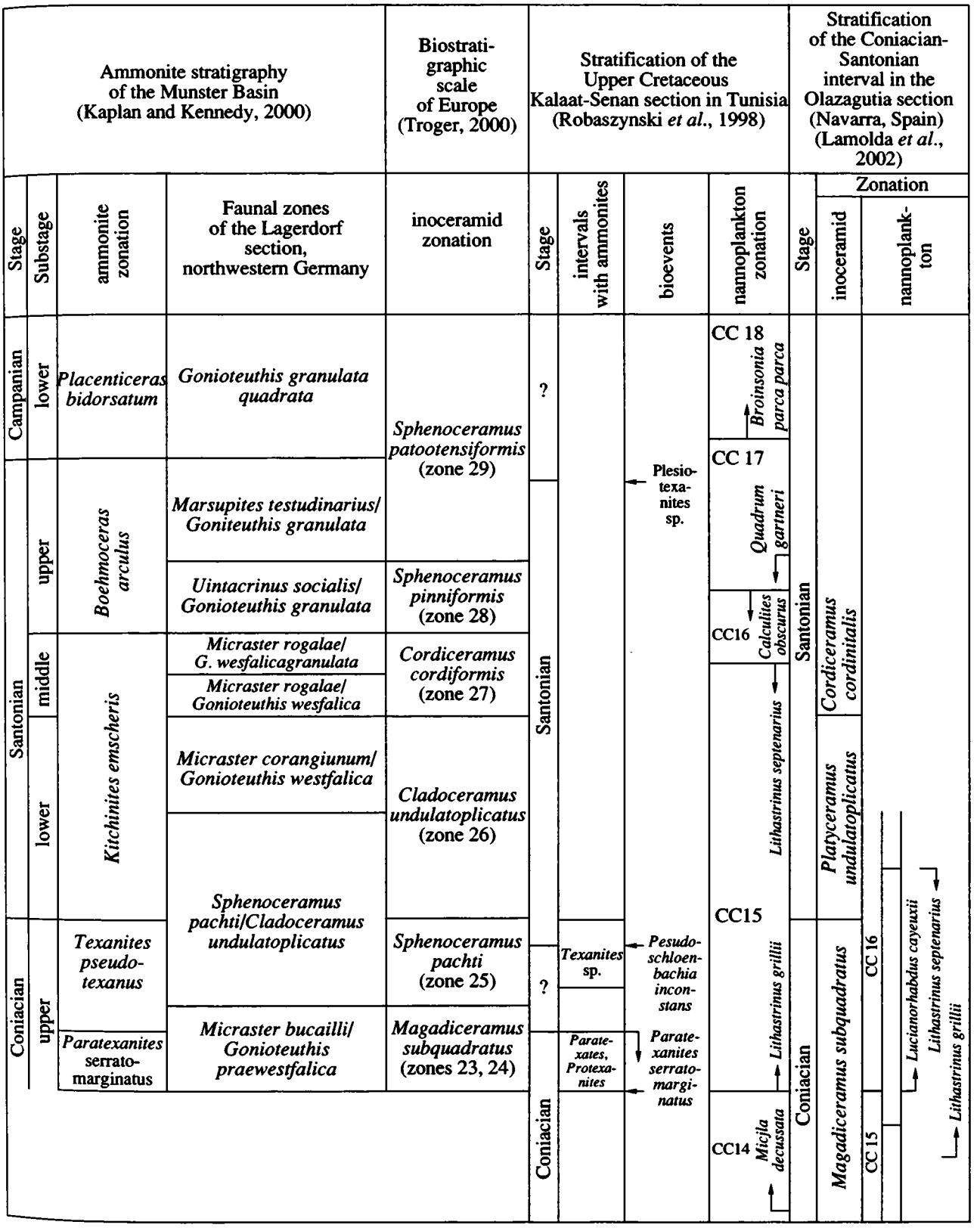
In the regional Upper Cretaceous stratigraphic scale of the East European platform, the Ardym Formation is correlated with standard *Bostrychoceras polyplocum* and *Didymoceras donezianum* zones. The new data show that the lower boundary of the formation should be placed at least inside the *Hoplitoplacenticeras marroti* Zone.

THE CONIACIAN–SANTONIAN BOUNDARY

As is evident from presented biostratigraphic data, there is a substantial discrepancy between ages of the Mozhzhevelovyi Ovrag and Mezino-Lapshinovka formations, which are estimated based on different fossil groups. Considerable difficulties in interpretation of calcareous nannoplankton assemblages are related, in our opinion, to three causes. These are (1) ambiguously understood and calibrated zonations of calcareous nan-

Changes in stratigraphic ranges of nannofossil zones and their correlation with zonations based on ammonites and inoceramids and with units of the standard scale




Ammonite stratigraphy of the Munster Basin (Kaplan and Kennedy, 2000)
Biostratigraphic scale of Europe (Troger, 2000)
Stratification of the Upper Cretaceous Kalaat-Senan section in Tunisia (Robaszynski et al., 1998)
Stratification of the Coniacian-Santonian interval in the Olazagutia section (Navarra, Spain) (Lamolda et al., 2002)
Stage
Substage
ammonite zonation
Faunal zones of the Lagerdorf section, northwestern Germany
inoceramid zonation
intervals with ammonites
bioevents
nannoplankton zonation
Zonation
inoceramid
nannoplankton
Campanian
lower
Placenticeras bidorsatum
Gonioteuthis granulata quadrata
Sphenoceramus patootensiformis (zone 29)
Santonian
upper
Boehmoceras arculus
Marsupites testudinarius/ Goniteuthis granulata
Uintacrinus socialis/ Gonioteuthis granulata
Sphenoceramus pinniformis (zone 28)
middle
Kitchinites emscheris
Micraster rogalae/ G. wesfalicagranulata
Micraster rogalae/ Gonioteuthis wesfalica
Cordiceramus cordiformis (zone 27)
lower
Micraster corangiunum/ Gonioteuthis westfalica
Cladoceramus undulatoplicatus (zone 26)
Sphenoceramus pachti/Cladoceramus undulatoplicatus
Coniacian
upper
Texanites pseudo-texanus
Sphenoceramus pachti (zone 25)
Paratexanites serrato-marginatus
Micraster bucailli/ Gonioteuthis praewestfalica
Magadiceramus subquadratus (zones 23, 24)
Stage
?
Santonian
?
Coniacian
Plesio-texa-nites sp.
Texanites sp.
Pesudo-schloen-bachia incon-stans
Parate-xates, Protexa-nites
Parate-xanites serrato-margi-natus
CC 18
Broinsonia parca parca
CC 17
Quadrum gartneri
CC16
Calculites obscurus
Lithastrinus septenarius
CC15
Lithastrinus grillii
CC14
Micula decussata
Stage
Santonian
Coniacian
Cordiceramus cordinitalis
Platyceramus undulatoplicatus
Magadiceramus subquadratus
CC 15
CC 16
Lucianorhabdus cayeuxii
Lithastrinus septenarius
Lithastrinus grillii

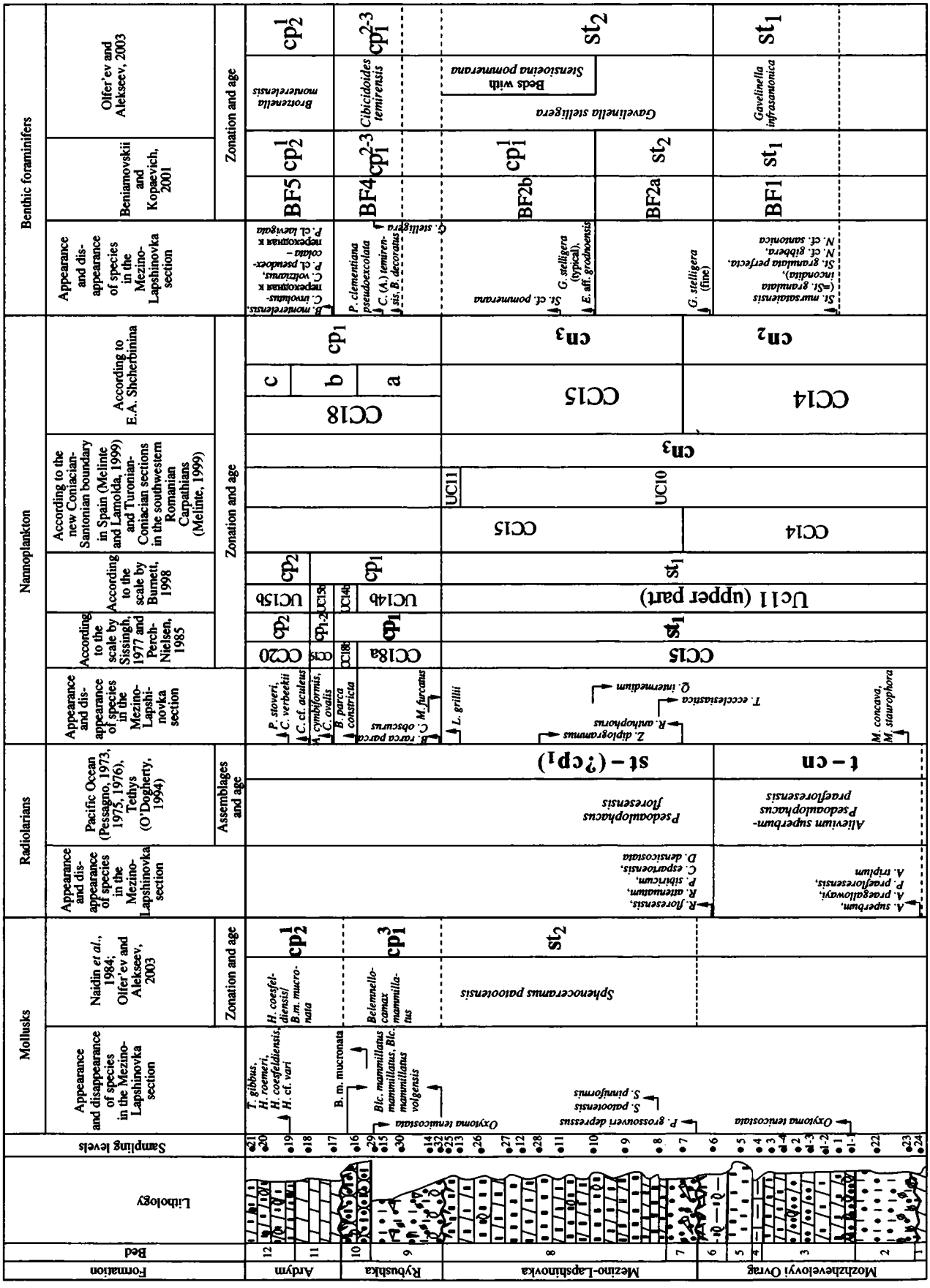

Formation
Bed
Lithology
Sampling levels
Mollusks
Naidin et al., 1984; Olfer'ev and Alekseev, 2003
Zonation and age
Appearance and disappearance of species in the Mezino-Lapshinovka section
Radiolarians
Pacific Ocean (Pessagno, 1973, 1975, 1976), Tethys (O'Dogherty, 1994)
Assemblages and age
Appearance and disappearance of species in the Mezino-Lapshinovka section
Nannoplankton
According to the scale by Sissingh, 1977 and Perch-Nielsen, 1985
According to the scale by Burnett, 1998
According to the new Coniacian-Santonian boundary in Spain (Melinte and Lamolda, 1999) and Turonian-Coniacian sections in the southwestern Romanian Carpathians (Melinte, 1999)
According to E.A. Shcherbinina
Appearance and disappearance of species in the Mezino-Lapshinovka section
Benthic foraminifers
Beniamovskii and Kopaevich, 2001
Olfer'ev and Alekseev, 2003
Appearance and disappearance of species in the Mezino-Lapshinovka section
Ardym
Rybushka
Mezino-Lapshinovka
Mozhzhevelovyi Ovrag
Sphenoceramus patootensis
Oxyjoma tenuicostata
Bic. mammillatus, Bic. mammillatus volgensis
B. m. mucronata
T. gibbus, H. roemeri, H. coesfeldiensis, H. cf. vari
Pseudoaulophacus floresensis
Alievium superbum-Pseudoaulophacus praefloresensis
st – (?cp1)
t – cn
Gavelinella stelligera
Beds with Stensioeina pommerana
Cibicidoides temirensis
Brotzenella monterelensis
Gavelinella infrasantonica
cp1
cp2
BF1
BF2a
BF2b
BF4
BF5
st1
st2
cn2
cn3
CCI4
CCI5
CCI8
UC11 (upper part)
UC10
UC11
UC14
UC15
CC18
CC20
Fig. 8. Ages estimated for sediments exposed in the Mezino-Lapshinovka quarry based on different fossil groups (legend as in Fig. 2).

Plate I

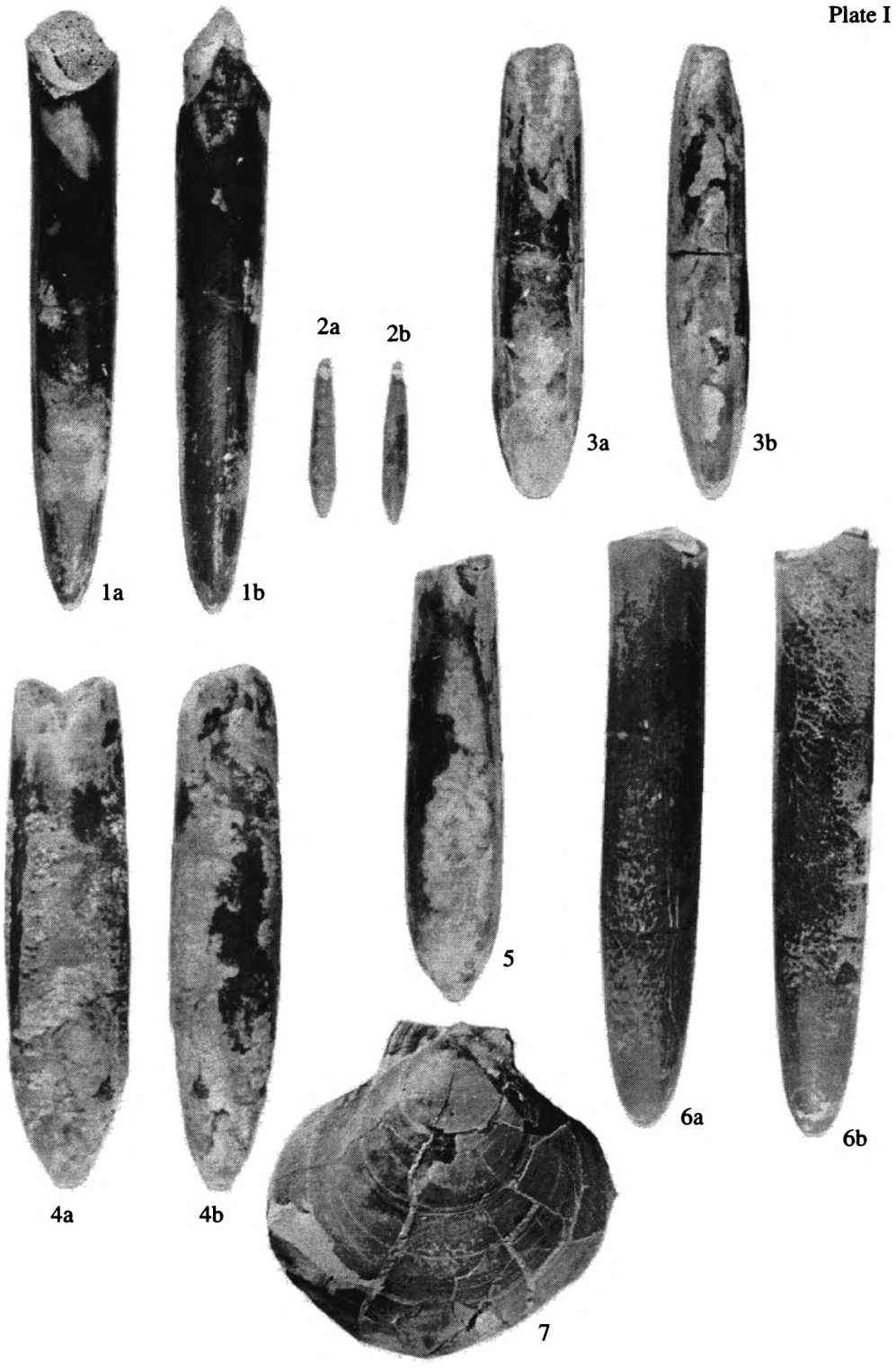


Plate I. Mollusks from the Mezino-Lapshinovka, Rybushka, and Ardym formations (natural size).

(1a, 1b) *Belemnitella praecursor* Stolley, specimen 4010, Bed 7: (a) dorsal view, (b) side view; (2a, 2b) *Actinocamax verus* cf. *fragilis* Arkhangelsky, specimen 4012, Bed 7: (a) ventral view, (b) side view; (3a, 3b) *Paractinocamax grossouvrei depressus* (Andreae), specimen 4008, Bed 7: (a) dorsal view, (b) side view; (4a, 4b) *Belemnellocamax mammillatus mammillatus* (Nilsson), specimen 4019, Bed 10: (a) dorsal view, (b) side view; (5) *Belemnellocamax mammillatus volgensis* Najdin, specimen 4005, Bed 10, dorsal view; (6a, 6b) *Belemnitella mucronata mucronata* Arkhangelsky, specimen 4015, Bed 12 (base): (a) dorsal view, (b) side view; (7) *Syncyclonema splendens* (Lahusen), specimen 4014, Bed 10.

Plate II

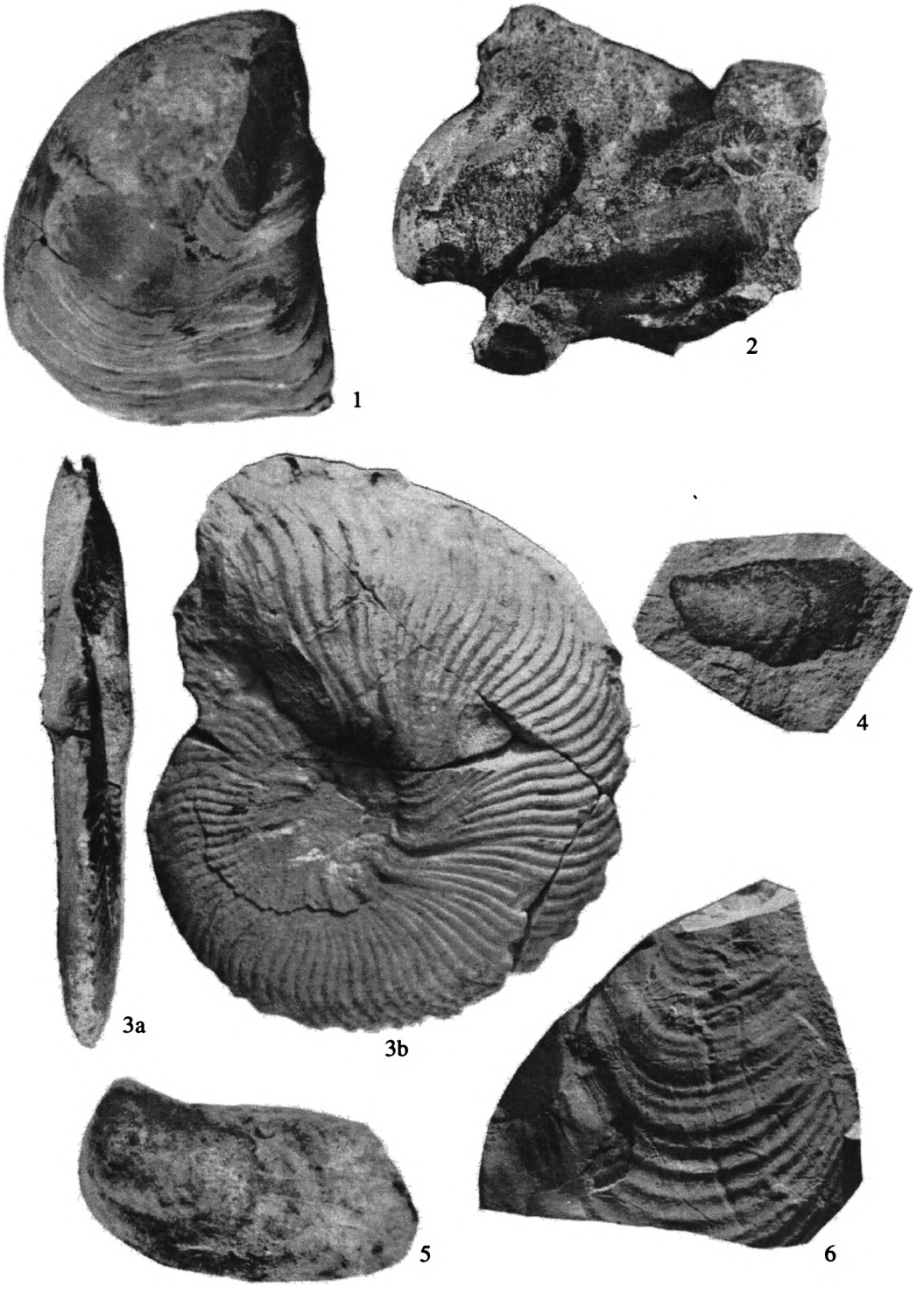


Plate II. Mollusks from the Rybushka and Ardym formations (natural size).

(1) *Monticulina vesicularis* (Lamarck), specimen 4011, Bed 12; (2) Accumulation of belemnite rostra in glauconitic sandstone, Bed. 10; (3a, 3b) specimen SVB 4037, lower part of Bed 12: (a) ventral view, (b) side view; (4) *Cataceramus barabini* (Morton), specimen 12/8, Bed 12; (5) *Cataceramus balticus* (Böhm.), specimen 12/3, Bed 12; (6) *Sphenoceramus patootensis*, specimen 8/38, Bed 8.

Plate III

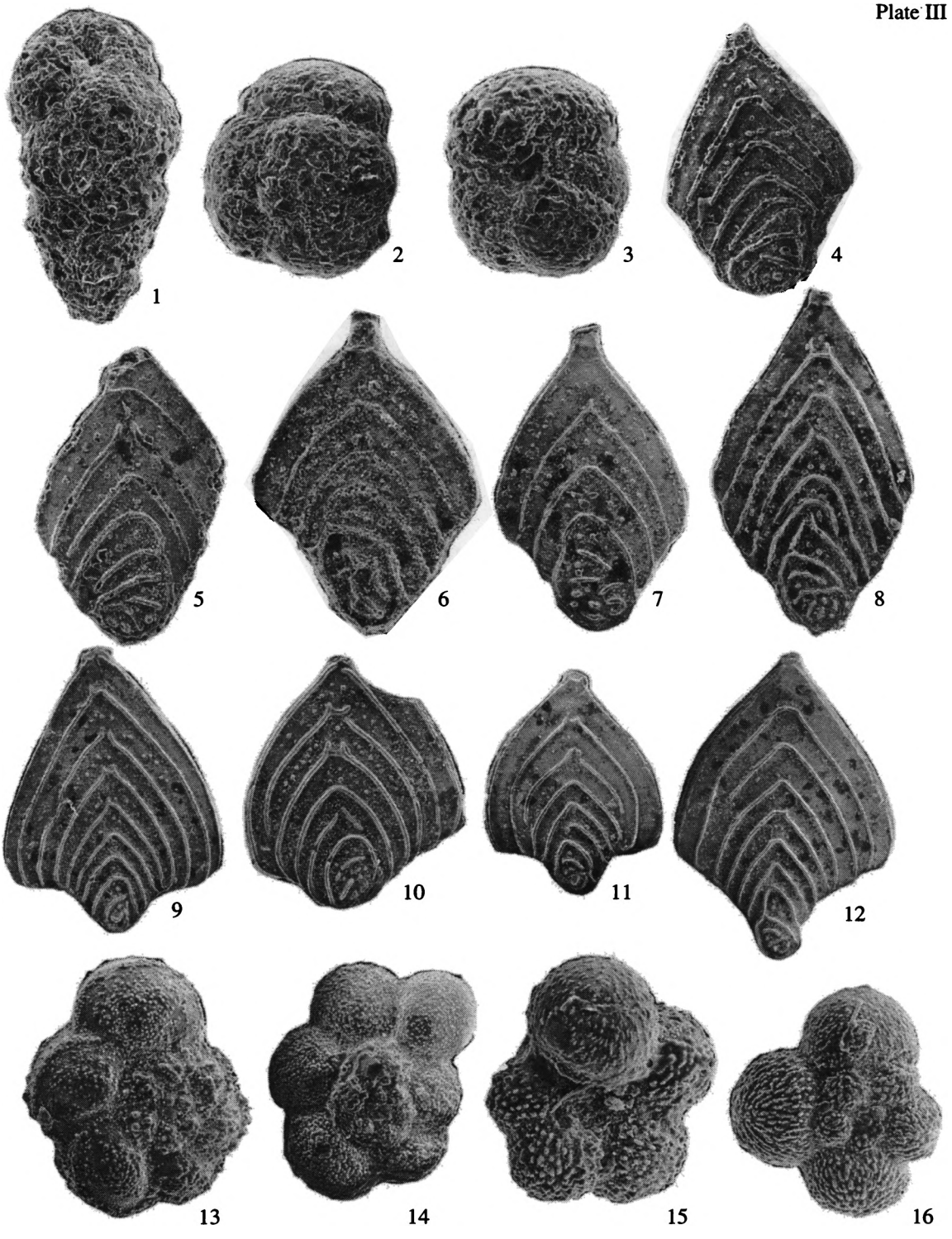


Plate IV. Benthic foraminifers from the Mozhzhevelovyi Ovrag, Mezino-Lapshinovka, and Ardym formations (genera *Neoflabellina, Stensioeina, Osangularia, Gavelinella, Eponides, Quadrimorphina, Praebulimina*).

(1) *Neoflabellina rugosa leptodisca* (Wedekind), specimen GIN ML 14; Sample 17, Bed 11, Ardym Formation; ×40; (2) *Neoflabellina* cf. *santonica* Koch, specimen GIN ML 15; Sample 1, Bed 3, Mozhzhevelovyi Ovrag Formation; ×100; (3) *Neoflabellina suturalis suturalis* (Cushman), specimen GIN ML 16; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×60; (4) *Stensioeina granulata granulata* (Olbertz), specimen GIN ML 17; spiral view; Sample 2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×100; (5) *Stensioeina granulata* cf. *perfecta* Koch, specimen GIN ML 18, spiral view; Sample 2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×100; (6) *Stensioeina granulata* cf. *perfecta* Koch, specimen GIN ML 19, spiral view; Sample 1/2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×130; (7) *Stensioeina mursataiensis* Vassilenko, specimen GIN ML 20, spiral view; Sample 1, Bed 3, Mozhzhevelovyi Ovrag Formation; ×110; (8) *Stensioeina mursataiensis* Vassilenko, specimen GIN ML 21, umbonal view; Sample 2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×110; (9) *Osangularia whitei* (Brotzen), specimen GIN ML 22, spiral view; Sample 2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×125; (10) *Gavelinella stelligera* (Marie), specimen GIN ML 23, spiral view; Sample 13, Bed 8, Mezino-Lapshinovka Formation; ×110; (11) *Gavelinella stelligera* (Marie), specimen GIN ML 24, spiral view; Sample 13, Bed 8, Mezino-Lapshinovka Formation; ×90; (12) *Gavelinella stelligera* (Marie), specimen GIN ML 25, umbonal view; Sample 13, Bed 8, Mezino-Lapshinovka Formation; ×90; (13) *Gavelinella stelligera* (Marie), specimen GIN ML 26, umbonal view; Sample 13, Bed 8, Mezino-Lapshinovka Formation; ×120; (14) *Gavelinella stelligera* (Marie), specimen GIN ML 27, side view; Sample 13, Bed 8, Mezino-Lapshinovka Formation; ×140; (15) *Eponides* aff. *grodnoensis* (Akimez), specimen GIN ML 28, spiral view; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×120; (16) *Eponides* aff. *grodnoensis* (Akimez), specimen GIN ML 29, side view; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×125; (17) *Eponides* aff. *grodnoensis* (Akimez), specimen GIN ML 30, side view; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×115; (18) *Quadrimorphina minuta* (Cushman), specimen GIN ML 31, umbonal view; Sample 26, Bed 8, Mezino-Lapshinovka Formation; ×150; (19) *Praebulimina ventricosa* (Brotzen), specimen GIN ML 32, spiral view; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×120; (20) *Praebulimina ventricosa* (Brotzen), specimen GIN ML 33, spiral view; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×130.

noplankton species that are sensitive in distribution to influence paleobiogeographic factors; (2) diversity in views on position of the Coniacian–Santonian boundary in West Europe; and (3) unfortunate selection of the GSSP for the boundary between stages (table).

At present, two nannoplankton scales are in use: the Tethyan zonation proposed by Sissingh (1977) and modified by Perch-Nielsen (1985) and the Boreal scale elaborated recently by Burnett (1998) mainly based on sections in England. The last scale becomes increasingly popular, although "it is lacking calibration of proposed stage boundaries based on levels substantiated by macrofaunal remains" (Naidin, 2002, p. 40).

In the first scale, a certain attention is paid to paleobiogeographic differentiation of communities and asynchronous appearance and disappearance levels of many index species in different parts of their distribution areas. Par example, C. von Salis demonstrated substantial difference in stratigraphic ranges of some taxa from Tethyan and Boreal realms beginning from the Coniacian, as it is shown in "The Cretaceous chronostratigraphic framework of European basins" (Hardenbol *et al.*, 1998, Table 5). Similar comments exist also in zonation elaborated by Burnett. All this creates difficulties for zonal subdivision of the Upper Cretaceous sections based on nannoplankton, particularly in the case of sequences accumulated in the eastern part of the spacious West European–Russian sea.

Even greater difficulties are caused by recent innovations concerning position of the Coniacian–Santonian boundary. Already at the First International Symposium of 1984 on Stage Boundaries of the Cretaceous System, which was held in Copenhagen, most of participants tended to correlate the lower boundary of the Santonian Stage with the first appearance either of inoceramid species *Cladoceramus undulatoplicatus* (Roem.) or ammonite subgenus *Texanites (Texanites)* emphasizing closeness or even synchronism of these biotic events (Birkelund *et al.*, 1984). In accordance with recommendations of the International Working

Plate III. Benthic foraminifers from the Mozhzhevelovyi Ovrag and Mezino-Lapshinovka formations (genera *Harena, Novatrix, Neoflabellina*) and planktonic foraminifers from the Mezino-Lapshinovka Formation.

(1) *Harena amanda* (Woloschinova), specimen GIN ML 1, spiral view, Sample 1, Bed 3, Mozhzhevelovyi Ovrag Formation; ×90; (2) *Novatrix obesa* (Reuss), specimen GIN ML 2, spiral view; Sample 1, Bed 3, Mozhzhevelovyi Ovrag Formation; ×100; (3) *Novatrix obesa* (Reuss), specimen GIN ML 3, umbonal view; Sample 1/2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×100; (4) *Neoflabellina* cf. *gibbera* (Wedekind), specimen GIN ML 4; Sample 1/2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×100; (5) *Neoflabellina* cf. *gibbera* (Wedekind), specimen GIN ML 5; Sample 1/2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×90; (6) *Neoflabellina* cf. *santonica* Koch, specimen GIN ML 6; Sample 1/2, Bed 3, Mozhzhevelovyi Ovrag Formation; ×90; (7) *Neoflabellina* cf. *santonica* Koch, specimen GIN ML 7; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×70; (8) *Neoflabellina* cf. *gibbera* (Wedekind), specimen GIN ML 8; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×60; (9) *Neoflabellina deltoidea* (Wedekind), specimen GIN ML 9; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×40; (10) *Neoflabellina deltoidea* (Wedekind), specimen GIN ML 10; Sample 13, Bed 8, Mezino-Lapshinovka Formation; ×40; (11) *Neoflabellina deltoidea* (Wedekind), specimen GIN ML 11; Sample 13, Bed 8, Mezino-Lapshinovka Formation; ×35; (12) *Neoflabellina suturalis suturalis* (Cushman), specimen GIN ML 12; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×40; (13) *Globotruncana globigerinoides* (Marie), specimen GIN ML 34, spiral view; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×115; (14) *Whiteinella* sp. or *Archaeoglobigerina* sp., specimen GIN ML 35, spiral view; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×95; (15) *Helvetiella* sp., specimen GIN ML 36, umbonal view; Sample 28, Bed 8, Mezino-Lapshinovka Formation; ×170; (16) *Rugoglobigerina rugosa* (Plummer), specimen GIN ML 37, spiral view; Sample 37, Bed 8, Mezino-Lapshinovka Formation; ×135.

Plate IV

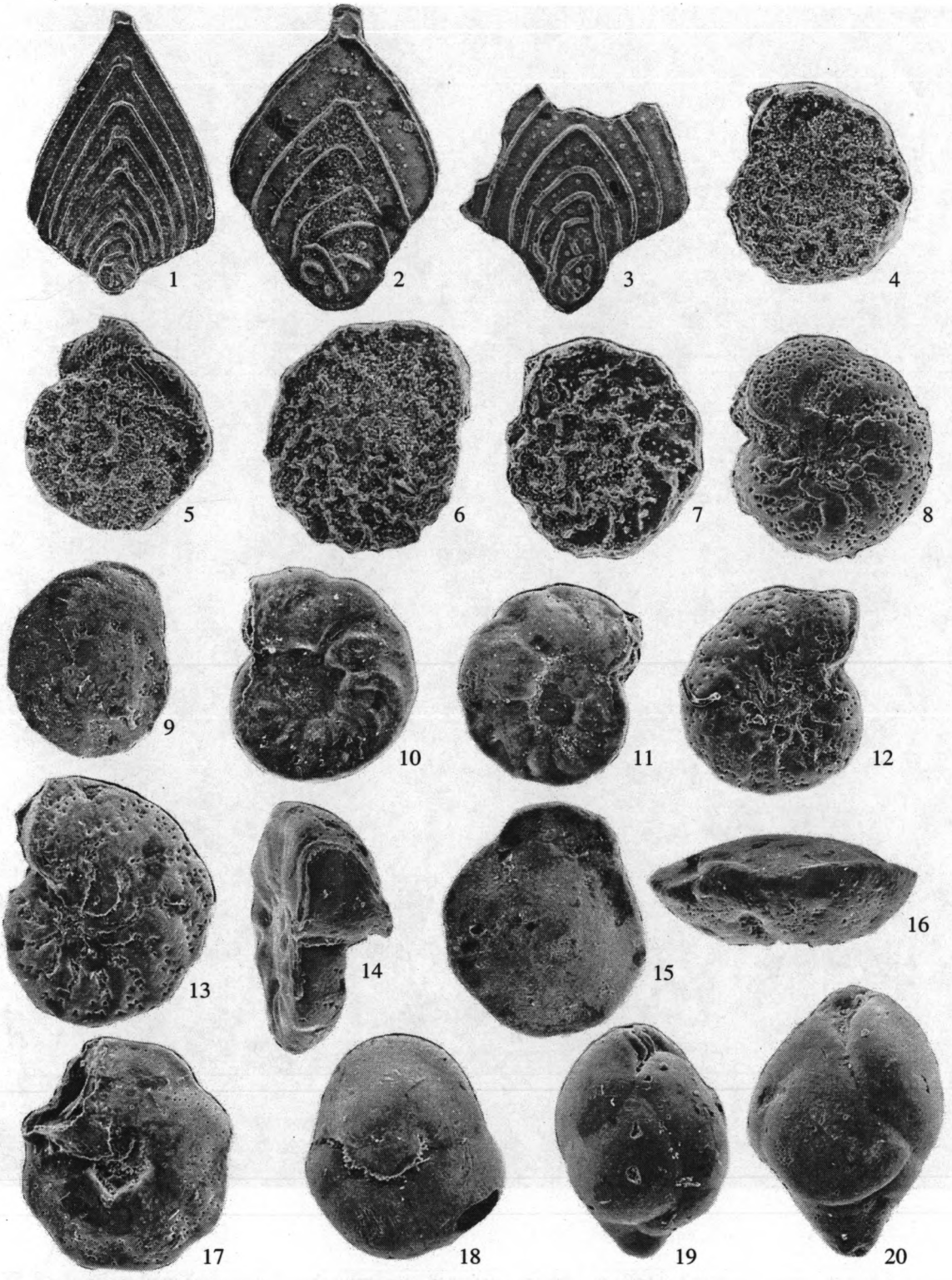


Plate V

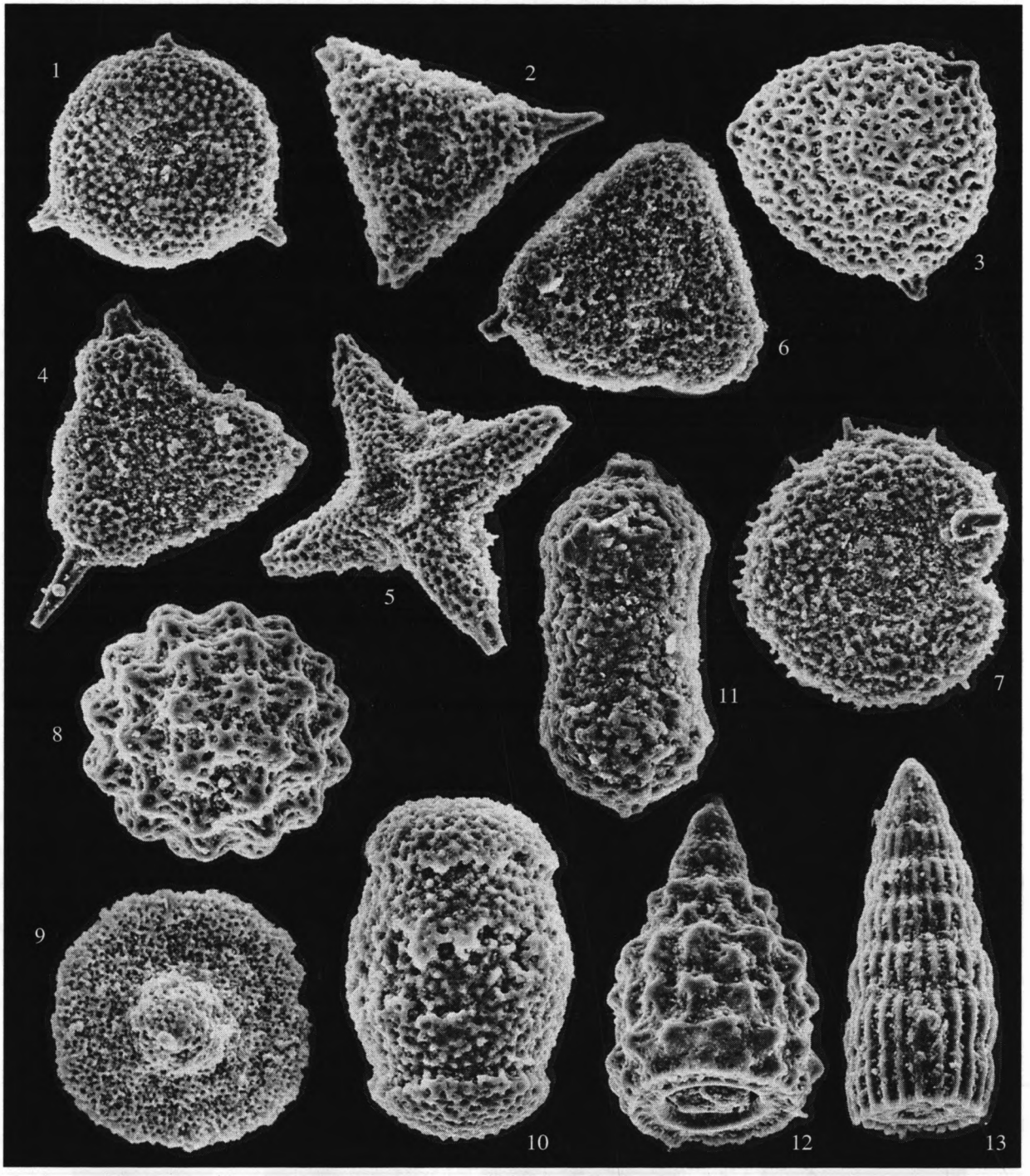


Plate V. Radiolarians from Turonian–Coniacian *Alievium superbum* and *Pseudoaulophacus praefloresensis* assemblages (Bed 2, Sample 22, figs. 9, 11, 13; Bed 3, Sample 1, figs. 1–2, 5–8; Bed 5, Sample 5, figs. 4, 10, 12).

(1, 2) *Pseudoaulophacus praefleresensis* Pessagno: (1) ×90, (2) ×75; (3) *Alievium* aff. *praegallowayi* Pess., ×90; (4) *Euchitonia* cf. *santonica* Lipman, ×100; (5) *Crucella cachensis* Pess., ×80; (6) *Pseudoaulophacus venadoensis* Pess., ×110; (7) *Orbiculiforma persenex* Pess., ×100; (8) *Praeconocaryomma universa* Pess., ×80; (9) *Cavaspongia* sp. cf. *C. fiskensis* Pess., ×110; (10) *Phaseliforma concentrica* (Lipman), ×100; (11) *Archaeospongoprunum bipartitum* Pess., ×80; (12) *Xitus asymbatos* (Foreman), ×100; (13) *Dictyomitra striata* Lipman, ×100.

Plate VI

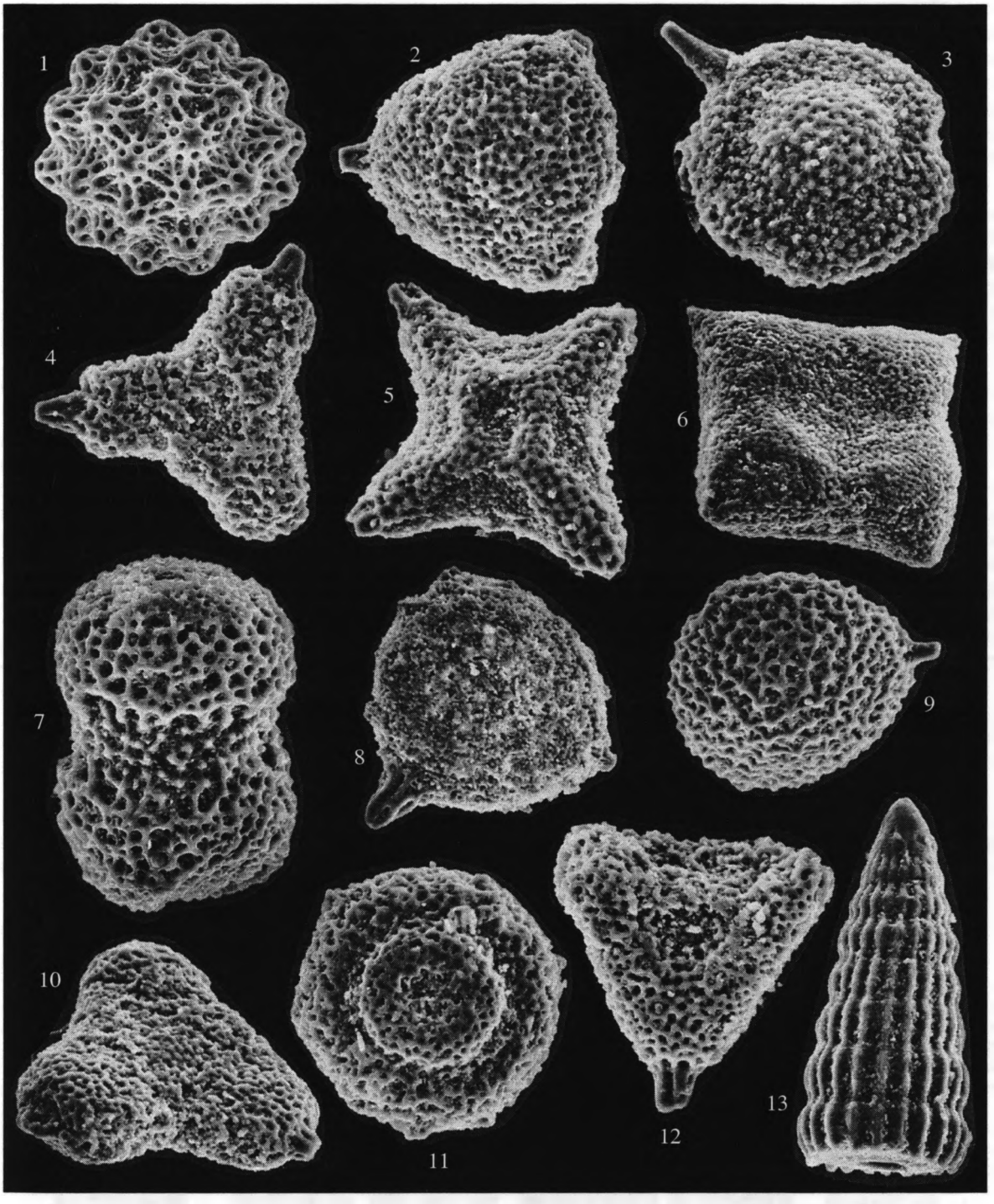
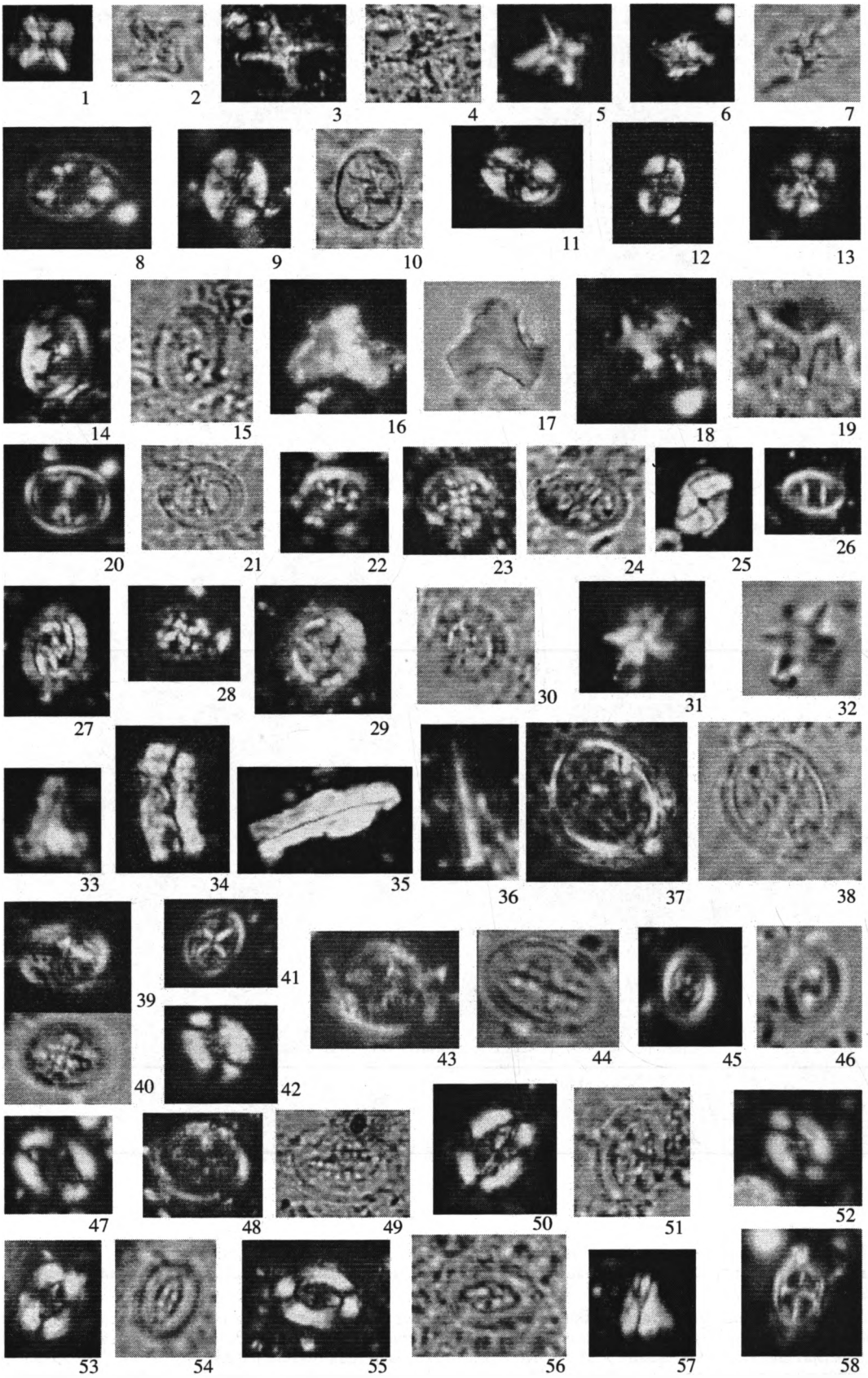


Plate VI. Radiolarians from Santonian *Pseudoaulophacus floresensis* assemblage (Bed 6, Sample 6, figs. 1–3; Bed 8, Sample 12, figs. 4–7) and from Turonian–Coniacian *Alievium superbum* and *Pseudoaulophacus praefloresensis* assemblages (Bed 3, Sample 1-1, figs. 8, 9; Bed 5, Sample5, figs. 10–12).

(1) *Praeconocaryomma universa* Pess., ×100; (2, 3) *Pseudoaulophacus floresensis* Pess., ×100; (4) *Rhopalastrum attenuatum* Lipm., ×80; (5) *Crucella* cf. *espartoensis* Pess., ×100; (6) *Histiastrum latum* Lipm.; ×90; (7) *Prunobrachium ornatum* (Lipm.), ×100; (8) *Cavaspongia euganea* (Squin.), ×90; (9) *Alievium superbum* (Squin.), ×90; (10) *Euchitonia* aff. *santonica* Lipm., ×100; (11) *Pseudoaulophacus* cf. *lenticulatus* (White), ×70; (12) *Pseudoaulophacus* cf. *floresensis* Pess., ×90; (13) *Dictyomitra striata* Lipman, ×80.

Plate VII


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58

Group on the Coniacian–Santonian Boundary, it was proposed at the Second International Symposium on Stage Boundaries of the Cretaceous System (Brussels, 1995) to be the base of the Santonian Stage, which corresponds to the first appearance level of *Cladoceramus undulatoplicatus* (Roem.).

In our opinion, selection of ammonites instead of inoceramids would be more reasonable to define that boundary, because the first appearance of the genus *Texanites* and, in particular, of *Texanites texanus* (Roem.) is synchronous with appearance of cardissoid sphenoceramids of the *Sphenoceramus pachti–S. cardissoides* group widespread in the Boreal realm. In the mentioned fundamental work "The Cretaceous chronostratigraphic framework of European basins" (Hardenbol *et al.*, 1998, Table 5), J. Thiery with colleagues correlated the base of the Santonian Stage with the first appearance of *Texanites texanus* (Roem.) in southern Europe and *T. gallicus* Coll. in northern Europe. In opinion of A. Dondt, this event is synchronous with appearance of inoceramids *Cladoceramus undulatoplicatus* (Roem.) in central Europe and *Sphenoceramus cardissoides* (Goldf.) in East Europe. This standpoint was basic for elaboration of the regional Upper Cretaceous stratigraphic scale of the East European platform (Olfer'ev and Alekseev, 2002, 2003).

Lamolda and Hancock (1996), who noted the joint occurrence of *Texanites* forms and Coniacian inoceramid species *Magadiceramus subquadratus* (Schlüt.) in Texas and northern Spain, opposed this decision. In addition, they emphasized the earlier appearance of inoceramids from the *Sphenoceramus pachti–S. cardissoides* group, as compared with first occurrence of *Cladoceramus undulatoplicatus* (Roem.) in Austria and Germany. Previously, similar facts were published by Tröger (1989) who defined the *Sphenoceramus pachti* Zone (25) at the base of the Santonian Stage and below *Cladoceramus undulatoplicatus* Zone (26). Subsequently, Kaplan and Kennedy (2000) correlated the *Sphenoceramus pachti* Zone with the *Texanites pseudotexanus* ammonite zone (in their opinion, an equivalent of the *Texanites texanus* Zone) and attributed it to the terminal part of the Coniacian Stage. Subsequently, Tröger (2002) agreed with the Coniacian age of the Zone 25.

At the meeting in Brussels, sections of the Olazagutia quarry in the Navarra Province of Spain, Seaford Head site in the Sussex County of England, and Ten Mile Creek in Texas, the United States, were recommended as candidates for the global stratotype of the boundary in question (Lamolda and Hancock, 1996), and the first section was favored later on.

In the Olazagutia quarry, which was demonstrated to participants of the International Symposium on the Coniacian–Santonian boundary (Lamolda *et al.*, 2002), the 160-m-thick sequence of marls and clayey limestones spans interval from the middle Coniacian to middle Santonian. Occurrence of *Magadiceramus subquadratus subquadratus* (Roem,.) that marks the base of the upper Coniacian is recorded at the level of 64.6 m. The overlying interval from 64.6 to 94.4 m is almost barren of macrofossils, except for echinoid species *Cardiaster integer* (Agass.) and *Micraster brevis* Desor. Nevertheless, this interval was attributed to the upper Coniacian *Magadiceramus subquadratus* Zone. The level of 94.4 m with *Cladoceramus undulatoplicatus* (Roem.) was taken for the base of the Santonian and, consequently, for the global stratotype of the stage lower boundary, although specimens of above taxon occur higher up to the level of 105.9 m.

The first ammonites in the section under consideration were found at levels of 139.2 and 151.6 m, where

Plate VII. Microphotographs of principal nannoplankton species from the Mezino-Lapshinovka section.

(1, 2) *Micula staurophora* (Gardet) Stradner, Sample 16: (1) polarized light, (2) nonpolarized light; (3–7) *Micula concavata* (Stradner) Verbeek: (3, 4) Sample 10: (3) polarized light, (4) nonpolarized light (5–76) Sample 16: (5, 6) polarized light, (7) nonpolarized light; (8) *Ahmuelerella octoradiata* Reinhardt, Sample 12, polarized light; (9–11) *Eiffellithus eximius* (Stover) Perch-Nielsen: (9) Sample 8, polarized light, (10, 11) Sample 10: (10) nonpolarized light, (11) polarized light; (12, 13) *Eiffellithus turriseiffeli* (Deflandre) Reinhardt, Sample 4: (12) polarized light, (13) nonpolarized ligfht; (14, 15) *Reinhardtites anthophorus* (Deflandre) Perch-Nielsen, Sample 13; (16–19) *Marthasterites furcatus* (Deflandre) Deflandre: (16, 17) Sample 9: (16) polarized light, (17) nonpolarized light, (18) Sample 2, polarized light, (19) Sample 5, nonpolarized light; (20, 21) *Reinhardtites* sp., Sample 10: (20) polarized light, (21) nonpolarized light; (22–24) *Chiastozygus bifarius* Bukry, Sample 8: (22, 23) polarized light, (24) nonpolarized light; (25) *Calculites ovalis* (Stradner) Prins et Sissingh, Sample 17, polarized light; (26) *Tranolithus orionatus* (Reinhardt) Perch-Nielsen, Sample 16, polarized light; (27) *Prediscosphaera arkhangelskyi* (Reinhardt) Perch-Nielsen, Sample 9, polarized light; (28) *Prediscosphaera ponticula* (Bukry) Perch-Nielsen, Sample 14, polarized light; (29) *Prediscosphaera grandis* Perch-Nielsen, Sample 15, polarized light; (30) *Prediscosphaera cretacea* (Arkhangelsky) Gartner, Sample 14, polarized light; (31, 32) *Lithastrinus grillii* Stradner, Sample 14: (31) polarized light, (32) nonpolarized light; (33, 35) *Lucianorhabdus maleformis* Reinhardt, Sample 19, polarized light; (34) *Lucianorhabdus cayeuxii* Deflandre, Sample 16, polarized light; (36) *Acuturris scotus* (Risatti) Wind et Wise, Sample 15, polarized light; (37, 38) *Kamptenerius magnificus* Deflandre, Sample 16: (37) polarized light, (38) nonpolarized light; (39, 40) *Broinsonia furtiva* Bukry, Sample 9: (39) polarized light, (40) nonpolarized light; (41) *Chiastozygus synquadriperforatus* Bukry, Sample 15, polarized light; (42) *Broinsonia parca constricta* Hattner, Sample 16, polarized light; (43, 44) *Broinsonia furtiva* Bukry, Sample 3, polarized light; (45, 46) *Zeugrhabdothus noeliae* Rood et al., Sample 6: (45) polarized light, (46) nonpolarized light; (47) *Broinsonia signata* (Noel) Noel), Sample 7, polarized light; (48, 49) *Arkhangelskiell* cf. *specillata* Vekshina, Sample 2: (48) polarized light, (49) nonpolarized light; (50, 51) *Broinsonia expansa* Wise et Watkins, Sample 13: (50) polarized light, (51) non-polarized light; (52) *Broinsonia* sp., Sample 13, polarized light; (53–56) *Broinsonia parca parca* (Stradner) Bukry, Sample 14: (53, 55) polarized light, (54, 56) non-polarized light; (57) *Ceratolithoides verbeeki* Perch-Nielsen, Sample 19, polarized light; (58) *Staurolithites imbricatus* (Gartner) Burnett, Sample10, polarized light.

they are represented by typical Santonian forms *Placenticeras polyopsis* (Dujard.) and *Pseudoschloenbachia inconstans* (de Gross.). *Texanites* forms are unknown in the Olazagutia section, but judging from the neighboring Villamartin section their range can correspond approximately to the upper half of the barren interval of 64.6 to 94.4 m. In the Villamartin section, *Magadiceramus* forms occur in the interval of 48.5 to 58.7 m, which is overlain by a sequence lacking inoceramids, but containing *Texanites* species, *Texanites hispanicus* Coll. included. Appearance of the last taxon is recorded at the level of 85.0 m, while *Cladoceramus undulatoplicatus* (Roem.) first appears at the level of 144.7 m.

Nannofossils of the Olazagutia section were examined in the interval of 75.5 to 122.0 m by Melinte and Lamolda (2002) who concluded that the Santonian lower boundary should be inside the Zone CC16, i.e., substantially higher than in the scale of Perch-Nielsen (1985), where it is in the terminal part of the Zone CC14. Under assumption that this section is accepted for the GSSP of Santonian Stage, one should displace sequences traditionally referred to the Santonian, in particular, the Mozhzhevelovyi Ovrag and Mezino-Lapshinovka formations, almost entirely down to the Coniacian, and such a decision would be far from being welcomed. As is shown above, a significant interval of the Olazagutia section is included into the Conaician Stage without any proofs, although it should belong mostly to the Santonian, if we took into account the very short range of the *Magadiceramus subquadratus* Zone. Consequently, the level where *Cladoceramus undulatoplicatus* was found first does not represent the "appearance level" of this species. Thus, the Olazagutia section is unsuitable for the GSSP of the Coniacian–Santonian boundary.

AGE OF THE *PTERIA* BEDS

Lahusen (1873) was first to discover gray marl with shells of *Avicula tenuicostata* Roem. in the right side of the Volga River and to trace them from Simbirsk to the Podval'e Village of the Samara region. A year later, Trautschold (1987) also noted presence of *Avicula* marls in the Novodevich'e Village area. Stratigraphic position of these rocks between underlying Turonian chalk with abundant inoceramids and overlying Senonian glauconitic marl was established by Pavlow (1897) in the Simbirsk region, who referred siliceous marls with *Avicula tenuicostata* Roem. to the Turonian. Later on, Arkhangel'skii (1912), who elaborated the regional Upper Cretaceous scheme for the Saratov region, defined the *Inoceramus patchi* (now *Sphenoceramus cardissoides*) and *Pteria tenuicostata* zones in the former *Avicula* sequence. He referred both zones to the lower Senonian. Discussing the problem of the *Pteria tenuicostata* Zone age and taking into account presence of lower Senonian *Actinocamax verus* Mill. and *Belemnitella precursor* Stoll., which occur together with *Pteria tenuicostata* (Roem.) known "only from the *Actinocamax* [now *Gonioteuthis*] *quadratus* Zone of England, i.e., from the basal part of the upper Senonian," Arkhangel'skii (1912, pp. 198–199) believed that the zone should be correlated with the lower–upper Santonian boundary interval, contrary to Pavlow (1900), who initially considered the *Avicula* Marls first as the Turonian and later as Emsherian in age. Milanovskii (1940) defined *Inoceramus cardissoides* and *Pteria tenuicostata* zones in the previously undivided sequence of *Avicula* Marls and referred them to the lower and upper Santonian, respectively. It should be noted that Milanovskii placed the boundary between these units in the Nizhnyaya Bannovka section based on erosion signs in the form of glauconitic sandstone bed "with the uneven lower surface and rhizoconcretions penetrating the underlying opokas" (Milanovskii, 1940, p. 198, Bed 10).

D.P. Naidin (Naidin, 1960, 1979; Gerasimov *et al.*, 1962; Najdin, 1969; Naidin and Kopaevich, 1977; Naidin *et al.*, 1984a, 1986) emphatically vindicated the Campanian age of beds with *Oxytoma tenuicostata* (Roem.), which he called the *Pteria* Beds, whereas other researchers considered them as Santonian in age. To solve the problem of the unit age, the Commission on the Cretaceous System of the USSR Interdepartmental Stratigraphic Committee organized four field symposia under scientific leadership of D.P. Naidin and G.N. Papulov with participation of specialists on different fossil groups. Sharing the standpoint of Arkhangel'skii on the probable partial correspondence of beds with *Pteria tenuicostata* (Roem.) to the *Actinocamax quadratus* Zone of England, Naidin correlated "*Pteria* Beds" with the *Gonioteuthis granulata quadrata* Zone of Germany and southwestern Russia, although *Oxytoma tenuicostata* (Roem.) is virtually unknown in the last region. Pasternak (1959) found the only specimen of this form in a core from borehole drilled near the Berezina Village in western Ukraine and attributed the relevant bed to the upper Santonian.

Some researchers doubted correctness of correlation proposed by Naidin because of the wide stratigraphic range of *Oxytoma tenuicostata* (Roem.) known from the upper part of the lower Santonian "banded sequence" in the Lysaya Gora section of Saratov and at the Pudovkino site (Ivanov and Pervushov, 1998). In addition, Naidin himself noted presence of this species at the same stratigraphic level in the Sengilei section near Ul'yanovsk. Moreover, referring to results of H. Frebold, V. Minke, and D. Donovan obtained in eastern Greenland, Naidin (1979, p. 19) emphasized abundance of *Oxytoma tenuicostata* (Roem.) in the lower Santonian layers "with inoceramids close to *Inoceramus cardissoides* (Goldf.)." It seems therefore that this *Oxytoma* form is actually of a wide stratigraphic range and occurs in the lower Campanian Substage. For instance, this form is characteristic of the *Quadrata* Chalk in England and Poland, being confined in the Krakow suburbs to the upper part of the *Gonioteuthis*

quadrata quadrata Zone, an equivalent of *Pilula* and *Senonensis* zones in Germany, and to higher stratigraphic levels. In addition, this taxon is known from *mammillatus* Beds of the Saratov region (Ivanov and Pervushov, 1998) and from their analogues in the Starodub area of the Bryansk region (materials by Olfer'ev). Glazunova (1972) found its abundant specimens of the taxon in basal layers of the upper Campanian *mucronata* Zone in the Ul'yanovsk region. Therefore, *Oxytoma tenuicostata* (Roem.) present in the *Quadrata* Chalk of West European sections cannot serve as evidence for the early Campanian age of *Pteria* Beds, which Naidin places at the base of the lower Campanian below the *Gonioteuthis quadrata quadrata* Zone of belemnite scale.

Naidin proposed to consider the Podval'e and Novodevich'e sites in the right side of the Volga River near Samara as the type area for the *Pteria* Beds. Defining the stratigraphic position of this unit within the Upper Cretaceous succession of the Volga River basin, he argued that it rests with a distinct hiatus upon the Santonian "banded sequence" and is overlain by "a sequence of bluish gray to gray opokas, siliceous clays, marls, glauconitic sands and sandstones containing rostra of belemnites *Belemnellocamax mammillatus* (Nils.) and *Belemnitella mucronata mucronata* Arkh. and belonging to the upper part of the lower Campanian" (Naidin, 1979, pp. 19–20). Precisely this stratigraphic position is characteristic of the Mezino-Lapshinovka Formation within the examined section.

Now, it is clear that the stratigraphic range of *Oxytoma tenuicostata* Biozone is extremely wide spanning at least the entire Santonian and Campanian. At the same time, the *Pteria* Beds of the Ul'yanovsk–Samara region (Sengilei, Podval'e, Usol'e, and Klimovka sections) or the Mezino-Lapshinovka Formation of the Saratov region, both yielding *Oxytoma tenuicostata* (Roem.) in abundance, cannot be attributed to the Campanian Stage. Data on all the examined orthostratigraphic groups and calcareous nannofossils indicate the late Santonian or even older age of the Mezino-Lapshinovka Formation.

CONCLUSION

Summarizing data on the reference section studied near the village of Mezino-Lapshinovka we arrived at the following inferences.

(1) Difference in ages estimated based on different fossils for sediments exposed in the Mezino-Lapshinovka quarry (Fig. 8) is a consequence of ambiguously interpreted ranges and boundary positions of units in the standard Cretaceous scale.

(2) Our studies show that ages estimated recently for radiolarian assemblages in different areas of the East European platform need a more reliable substantiation.

(3) The available parallel nannoplankton-based zonal scales elaborated for of the Mediterranean and West European sections cannot be directly used for subdivision of the Upper Cretaceous sections in the Russian plate until a thorough study of this microphytoplankton group in reference sections of different structural–facies zones.

(4) Acceptance of the GSSP for the Coniacian–Santonian boundary in the Olazagutia section at the level proposed by the International Working Group (Lamolda *et al.*, 2002) will result in displacement of East European sequences with inoceramids of the *Sphenoceramus cardissoides–S. pachti* group from the lower Santonian Substage down to the upper Coniacian Substage. The large interval of the Olazagutia section is included into the Coniacian Stage without sufficient substantiation, and it would be unreasonable to select the GSSP for the Coniacian lower boundary in this section.

ACKNOWLEDGMENTS

We are grateful to D.P. Naidin for assistance in determination of ammonites and belemnites, E.Yu. Baraboshkin for donated field materials on the Novodevich'e section, R.A. Voinova for the laboratory treatment of micropaleontolgical samples, and A.N. Reimers for his help in photographing foraminifers. The work was supported by the Russian Foundation for Basic Research, project nos. 02-05-64576, 03-05-64330, 03-05-64425, by the Ministry of Education of the Russian Federation for scientific researches of young scientists in leading research–educational teams, project RD 02 1.5–483, and by the Federal Program "Integratsiya."

Reviewer I. A. Basov

REFERENCES

1. V. S. Akimets, V. N. Beniamovskii, and L. F. Kopaevich, "Cretaceous System. Upper Series. Western European Part of the USSR and Western Kazakhstan," in *Practical Manual on Microfauna of the USSR*, Vol. 5, *Mesozoic Foraminifers* (Nedra, Moscow, 1991), pp. 161–192 [in Russian].
2. A. D. Arkhangel'skii, "Upper Cretaceous Sediments of the Eastern European Part of Russia," in *Materials on Geology of Russia* (Imper. Akad. Nauk, St. Petersburg, 1912), Vol. 25 [in Russian].
3. H. W. Bailey, A. S. Gale, R. N. Mortimore, *et al.*, "Biostratigraphiocal Criteria for the Recognition of the Coniacian to Maastrichtian Stage Boundaries in the Chalk of North-West Europe, with Particular Reference to Southern England," Bull. Geol. Soc. Denmark **33**, 31–39 (1984).
4. V. N. Beniamovskii and L. F. Kopaevich, "Bentic Foraminiferid Zonation in the Late Santonian - Maastrichtian of the European Paleobiogeographical Area (EPA)," Zbl. Geol. Paläontol., Teil 1, Nos. 11–12, 1149–1161 (1998).

5. V. N.Beniamovskii and L. F. Kopaevich, "Benthic Foraminifer Zonation in the Campanian–Maastrichtian of the European Paleobiogeographic Region," Stratigr. Geol. Korrelyatsiya **9** (6), 49–70 (2001) [Stratigr. Geol. Correlation **9**, 570–590 (2001)].
6. V. N. Beniamovskii, L. F. Kopaevich, V. S. Akimets, *et al.*, "Upper Cretaceous Stratigraphy of the Ul'yanovsk Volga Region Based on Foraminifer," Izv. Akad. Nauk SSSR, Ser. Geol., No. 5, 65–74 (1988).
7. T. Birkelund, J. M. Hancock, M. B. Hart, *et al.*, "Cretaceous Stage Boundaries—Proposal," Bull. Geol. Soc. Denmark **33**, 3–20 (1984).
8. M. Ya. Blank, "Class Gastropoda," in *Atlas of the Upper Cretaceous Fauna of the Donbas* (Nedra, Moscow, 1974), pp. 118–157 [in Russian].
9. J. A. Burnett, "Upper Cretaceous," in *Calcareous Nannofossil Biostratigraphy* (Cambridge Univ. Press, London, 1998), pp. 132–164.
10. W. K. Christensen, "Upper Cretaceous Belemnitellids from the Bastad Basin, Southern Sweden," Geol. Fören. Stockholm Förhandl. **115**, 39–57 (1993).
11. P. H. Doeven, "Cretaceous Nannofossil Stratigraphy and Paleoecology of the Canadian Atlantic Margin," Bull. Geol. Surv. Can., No. 356 (1983).
12. P. A. Gerasimov, E. E. Migacheva, D. P. Naidin, *et al.*, "Jurassic and Cretaceous Sediments of the Russian Platform," in *Essays on Regional Geology of the USSR* (MGU, Moscow, 1962), Issue 9 [in Russian].
13. E. A. Glazunova, "Pelecypods," in *Cretaceous Stratigraphy and Fauna of the West Siberian Lowland* (VSEGEI, Leningrad, 1960), pp. 134–177 [in Russian].
14. E. A. Glazunova, *Paleontological Substantiation of Cretaceous Stratigraphy in the Volga Region* (Nedra, Moscow, 1974) [in Russian].
15. J. M. Hancock and A. S. Gale, "Campanian Stage," Bull. Inst. Roy. Sci. Natur. Belgique.Sci. Terre **66**, 103 (1996).
16. J. Hardenbol, J. Thierry, M. B. Farley, *et al.*, "Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins," SEPM (Soc. Sedimentol. Geol.) Spec. Publ. **60**, Charts 1, 4 (1998).
17. A. V. Ivanov, *Marinaculates, a New Problematic Type of Animals from Cretaceous and Paleogene Deposits of Russia* (GosUNTS Kolledzh, Saratov, 1995) [in Russian].
18. A. V. Ivanov and E. M. Pervushov, "Santonian–Campanian Sponge Horizons and '*Pteria* Beds' of the Saratov Volga Region," in *Deep Layers of the Volga and Caspian Regions* (1998), Issue 17, pp. 24–30 [in Russian].
19. A. V. Ivanov and E. V. Popov, "Complex study of Upper Cretaceous deposits from the lower Volga region, Russia," in *Recent Advances in the Study of Cretaceous Sections. Intern. Seminar* (Chennai, 1998), p. 32.
20. U. Kaplan and W. Kennedy, "Santonian Ammonite Stratigraphy of the Münster Basin, NW Germany," Acta Geol. Polonica **50** (1), 99–117 (2000).
21. W. J. Kennedy, "Ammonite Faunas and the "Standard Zones" of the Cenomanian To Maastrichtian Stages in Their Type Areas, with Some Proposals for Definition of the Stage Boundaries by Ammonites, Bull. Geol. Soc. Denmark **33**, 147–161 (1984).
22. W. Koch, "Biostratigraphie in Der Oberkreide Und Taxonomie Von Foraminiferen," Geol. Jahrb., No. A38, 11–123 (1977).
23. S. P. Kotsyubinskii and O. V. Savchinskaya, "Class Bivalvia," in *Atlas of the Upper Cretaceous Fauna of the Donbas* (Nedra, Moscow, 1974), pp. 67–118 [in Russian].
24. I. I. Lahusen, "Description of Fossils from White Chalk of the Simbirsk Region," in *Scientific–Historical Collection of Paper Published by the Geological Institute to Its 100 Year Anniversary* (Imper. Akad. Nauk, St. Petersburg, 1873), pp. 219–277 [in Russian].
25. M. A. Lamolda and J. M. Hancock, "The Santonian Stage and Substages," Bull. Inst. Roy. Sci. Natur. Belgique. Sci. Terre **66**, 95–102 (1996).
26. M. A. Lamolda, J. Gallemi, R. Martinez, *et al.*, in *Meeting on the Coniacian–Santonian Boundary. Bilbao, September 14–16* (Bilbao, 2002), pp. 33–66.
27. M. S. Melinte, "Turonian–Coniacian Nannofossil Events in the East and South Carpathians (Romania)," Rev. Esp. Micropaleontol. **31** (3), 369 (1999).
28. M. S. Melinte and M. A. Lamolda, "Calcareous Nannofossil Markers of the Coniacian/Santonian Boundary Interval, a Review," in *Meeting on the Coniacian–Santonian Boundary, Bilbao, September 14–16* (Bilbao, 2002), pp. 15–16.
29. N. P. Mikhailov, *Upper Cretaceous Ammonites from the Southern European Part of the USSR and Their Significance for Zonal Stratigraphy* (Akad. Nauk SSSR, Moscow, 1951) [in Russian].
30. E. E. Milanovskii, *Geology of the Middle and Lower Volga Region* (Gostoptekhizdat, Moscow, 1940) [in Russian).
31. D. P. Naidin, "The Stratigraphy of the Upper Cretaceous of the Russian Platform," Contrib. Geol. Stockholm **6** (4), 39 (1960).
32. D. P. Naidin, *Upper Cretaceous Belemnites of the Russian Platform and Adjeacent Regions* (MGU, Moscow, 1964) [in Russian].
33. D. P. Naidin, "On the Santonian–Campanian Boundary on the Platform," in *The Santonian–Campanian Boundary in the East European Platform* (UNTS AN SSSR, Sverdlovsk, 1979), pp. 7–23 [in Russian].
34. D. P. Naidin, "Once More on the Santonian–Campanian Boundary. Article 2. Stratigraphic Potential of *Pachydiscus neubergicus* (Hauer)," Byull. Mosk O–va Ispyt. Prir. Otd. Geol., **77** (4), 33–45 (2002).
35. D. P. Naidin, V. N. Beniamovskii, and L. F. Kopaevich, "Upper Cretaceous Biostratigraphy of the European Paleobiogeographic Region," Vestn. MGU. Ser. Geol., No. 5, 3–15 (1984a).
36. D. P. Naidin, V. N. Beniamovskii, and L. F. Kopaevich, *Investigation Methods of Transgressions and Regressions* (MGU, Moscow, 1984b) [in Russian].

37. D. P. Naidin and L. F. Kopaevich, "Zonal Subdivisions of the Upper Cretaceous in European Paleobiogeographic region," Byull. Mosk. O–va Ispyt Prir. Otd. Geol. **52** (5), 92–112 (1977).

38. D. P. Naidin and N. S. Morozov, "Regional Stratigraphic Essays. I. East European Platform. Upper Series" in *Stratigraphy of the USSR. Cretaceous System. Half-Volume 1* (Nedra, Moscow, 1986), pp. 83–108 [in Russian].

39. D. P. Naidin, V. P. Pokhialainen, Yu. A. Kats, *et al.*, *Cretaceous Period. Paleogeography and Paleoceanology* (Nauka, Moscow,1986) [in Russian].

40. D. P. Najdin, "Biostratigraphie und Paläogeographie der Oberen Kreide der Russischen Tafel," Geol. Jahrb. **87**, 157 (1969).

41. G. S. Odin, *The Campanian–Maastrichtian Stage Boundary: Characterization of Tercis-les-baines, France: Correlation with Europe and Other Countries* (USGS, Amsterdam, 2001).

42. L. O'Doherty, *Biochronology and Paleontology of Mid-Cretaceous Radiolarians from Northern Appennines (Italy) and Betic Cordillera (Spain)* (Lausanne, 1994).

43. A. G. Olfer'ev and A. S. Alekseev, "The Global Upper Cretaceous Scale," Stratigr. Geol. Korrelyatsiya **10** (3), 66–80 (2002) [Stratigr. Geol. Correlation **10**, 270–285 (2002)].

44. A. G. Olfer'ev and A. S. Alekseev, "Biostratigraphic Zonation of the Upper Cretaceous in the East European Platform," Stratigr. Geol. Korrelyatsiya **11** (2), 75–101 (2003) [Stratigr. Geol. Correlation **11**, 172–198 (2003)].

45. A. G. Olfer'ev, V. S. Vishnevskaya, L. I. Kazintsova, *et al.*, "New Data on the Upper Cretaceous Deposits in the North of Moscow Region," Stratigr. Geol. Korrelyatsiya **8** (3), 64–82 (2000) [Stratigr. Geol. Correlation **8**, 270–288 (2000)].

46. M. N. Ovechkina, "Upper Cretaceous Stratigraphy of the Saratov Volga Region Based on Calcareous Nannoplankton," in *Cretaceous System of Russia. Problems of Stratigraphy and Paleogeography* (MGU, Moscow, 2002), p. 75 [in Russian].

47. C. I. Pasternak, *Biostratigraphy of Cretaceous Deposits in the Volyn'–Podoliya Plate* (Akad. Nauk UkrSSR, Kiiv, 1959) [in Ukrainian].

48. A. P. Pavlow, *Voyage Géologique par la Volga de Kazan á Tzaritsyn. Guide des excurs. du VII Congr. Géol. Intern., Vol. 20* (St. Petersburg, 1987).

49. A. P. Pavlow, "The Emscher Horizon among Upper Cretaceous Deposits of Eastern Russia and Coastal Facies of the Russian Turonian and Senonian" Bull. Soc. Imper. Natur. Moscou **14**, (1–2), 35–37 (1900).

50. K. Perch-Nielsen, "Mesozoic Calcareous Nannofossils," in *Plankton Stratigraphy* (Cambridge Univ. Press, Cambridge, 1985), Vol. 1, pp. 329-426.

51. E. M. Pervushov, A. V. Ivanov, and E. V. Popov, "Local Stratigraphic Scheme of Upper Cretaceous Deposits in the Right Side of the Volga River," Trudy NIIG Saratov. Gos. Univ. Nov. Ser. **1**, 112–113 (1998a).

52. E. M. Pervushov, A. V. Ivanov, and E. V. Popov, "Project of the Local Stratigraphic Scheme for Upper Cretaceous Deposits in the Volga Region" in *Proceedings Scientific Conf.: Geological Sciences—98* (Gos. UNTS Kolledzh, Saratov, 1998b), p. 43 [in Russian].

53. E. M. Pervushov, A. V. Ivanov, and E. V. Popov, *et al.*, "Complex Study of Reference Sections—a Basis for an Elaboration of the Local Upper Cretaceous Stratigraphic Scheme," in *Intern. Scientific Conf.: Geology and Mineral Resources of the Southern Russian Plate* (NIIGG, Saratov, 1998), pp. 53–54 [in Russian].

54. E. Pessagno, "Upper Cretaceous *Spumellariina* from the Great Valley Sequence, California Coast Range," Bull. Am. Paleontol. **63** (276), 49–101 (1973).

55. E. Pessagno, "Upper Cretaceous Radiolaria from DSDP Site 175," in *Init. Repts. of the DSDP* (US Govt. Print. Office, Washington, 1975), Vol. 29, pp. 1011–1029.

56. E. Pessagno, "Radiolarian Zonation and Stratigraphy of the Upper Cretaceous Portion of the Great Valley Sequence," Micropaleotology Spec. Publ., No. 2, 1 (1976).

57. E. V. Popov and A. V. Ivanov, "Research Result from a Series of the Campanian Deposits, Saratov Region, Russia," in *Proceedings of the 5-th Intern. Cretaceous Symposium* (Freiberg, 1996), p. 148.

58. E. V. Popov and A. V. Ivanov, "Preliminary Results of the Study of Campanian Deposits in the Lower Volga Region," in *Youth and Problems of Geology* (Tomsk, 1997), p. 36.

59. F. Robaszynski, J. M. Gonzales Donoso, D. Linares, *et al.*, "The Upper Cretaceous of the Kalaat Senan Region, Central Tunisia. Integrated Litho-Biostratigraphy Based on Ammonites, Planktonic Foraminifera and Nannofossils Zones from Upper Turonian to Maastrichtian," Bull. Centre Rech. Elf. Explor. Prod. **22** (2), 359–490 (2000).

60. P. H. Roth, "Cretaceous Nannoplankton Biostratigraphy of the Northwestern Atlantic Ocean," in *Init. Repts. of the DSDP* (US Govt. Print. Office, Washington, 1978), Vol. 44, pp. 731–759.

61. A. Schaaf, "Radiolaria from DSDP, Leg 89," in *Init. Repts. of the DSDP* (US Govt. Print. Office, Washington, 1986), Vol. 89, pp. 321–326.

62. J. Schönfeld, "Stratigraphie und Ökologie benthischer Foraminiferen im Schreibkreide-Richtprofil von Lügerdorf/Holstein," Geol. Jahrb., No. A117, 1–139 (1990).

63. W. Sissingh, "Biostratigraphy of Cretaceous Calcareous Nannoplankton," Geol. Mijnbouw. **56** (3), 37–65 (1977).

64. W. Sissingh, "Microfossil Biostratigraphy and Stage-Stratotypes of the Cretaceous," Geol. Mijnbouw. **57** (3), 433–440 (1978).

65. *Stratigraphic Code* (VSEGEI, St. Petersburg, 1992) [in Russian].

66. H. Trautschold, "Die Scheidelinie zwischen Jura und Kreide in Russland," Bull. Soc. Natur. Moscou, No. 3, 150–164 (1874).

67. K.-A. Tröger, "Problems of Upper Cretaceous Inoceramid Biostratigraphy and Palaeobiogeography in Europe

and Western Asia," in *Proceedings of the 3rd International Cretaceous Symposium* (E. Schweitzerbartische Verlagsbuchhandlung, Stuttgart, 1989), pp. 911–930.

68. K.-A. Tröger, "Upper Cretaceous Inoceramids of Europe," Mem. Geol. Soc. India, No. 46, 119–130 (2000).

69. K.-A. Tröger, "Biostratigraphy of inoceramids at the Coniacian/Santonian boundary in Germany, in *Proceedings of the Meeting on the Coniacian–Santonian Boundary, Bilbao, September, 14-16, 2002*, pp. 25–26.

70. J. W. Verbeek, "Calcareous Nannoplankton Biostratigraphy of Middle and Upper Cretaceous Deposits in Tunisia, Southern Spain and France," Utrecht Micropaleontol. Bull., No. 16, 157 (1977).

71. M. Wagreich, "Correlation of Late Cretaceous Nannofossil Zones with Ammonite Zones and Planktonic Foraminiferas: the Austrian Gosau Section," Cretaceous Res. **13**, 505–516 (1992).

72. S. W. Wise, "Mesozoic and Cenozoic Calcareous Nannofossils Recovered by Deep Sea Drilling Project Leg 71 in Falkland Plateau, Southwest Atlantic Ocean," in *Init. Repts. of the DSDP* (US Govt. Print. Office, Washington, 1983), Vol. 71, pp. 481–550.

73. H. A. Woods, "Monograph of the Cretaceous Lamellibranchia of England," Palaeontogr. Soc. London **2**, 57–96 (1905).

74. L. N. Yakushin and A. V. Popov, *Abridged Atlas of Late Cretaceous Bivalves from the Southeastern Part of the East European Platform* (Nauchnaya Kniga, Saratov, 2001) [in Russian].

Stratigraphy and Geological Correlation, Vol. 12, No. 6, 2004, pp. 637–646. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 12, No. 6, 2004, pp. 103–112.
Original Russian Text Copyright © 2004 by Golovina, Goncharova, Rostovtseva.
English Translation Copyright © 2004 by MAIK "Nauka/Interperiodica" (Russia).

New Data on the Middle Miocene Biostratigraphy (Nannofossils, Mollusks) and Lithology of the Tamanskii Peninsula and Western Ciscaucasia

L. A. Golovina*, I. A. Goncharova, and Yu. V. Rostovtseva*****

* *Geological Institute, Russian Academy of Sciences, Moscow, Russia*

** *Paleontological Institute, Russian Academy of Sciences, Moscow, Russia*

*** *Moscow State University, Moscow, Russia*

Received January 16, 2003; in final form, September 22, 2003

Abstract—Lithology and distribution of nannofossils and mollusks in two continuous sections (anticline of the Mt. Zelenskii, Tamanskii Peninsula, and the Pshekha River section, Western Ciscaucasia) of the upper Chokrakian–lower Sarmatian deep-water sediments have been studied. Sediments in the Mt. Zelenskii anticline core are dated back to the late Chokrakian based on molluscan records. In the interval of the upper Konkian–lowermost Sarmatian, there is recorded flourishing of the monothetic *Reticulofenestra pseudoumbilica* assemblage. In the studied sections, the upper boundary of the Konkian Horizon is suggested to be at the top of the marker bed with abundant *Reticulofenestra pseudoumbilica* Gartner, and the lower boundary is placed at the first occurrence level of polyhaline benthic or planktonic fossils. The first occurrence of *Abra reflexa* (Eichw.) can be regarded as indicative of the Konkian level in the deep-water sediments barren of mollusks. The general lithologic trend and analyzed fauna are used to elucidate the sedimentation regime during the late Chokrakian–middle Sarmatian and to reconstruct hydrologic peculiarities of the basin at that time. Accumulation of fine-grained peloid (cyanobiontic) limestones took place in deeper parts of the basin during the late Chokrakian–Karaganian, when the marine water circulation was disturbed. Algal sediments intensively accumulated parallel to clay sedimentation in shoal settings and likely in the entire euphotic zone of the basin.

Key words: Middle Miocene, Eastern Paratethys, Chokrakian, Karaganian, Konkian, Sarmatian, mollusks, nannofossils.

INTRODUCTION

One of disputable problem concerning stratigraphy of Neogene sediments in the Eastern Paratethys is correlation between the regional and Mediterranean stages. Difficulties in solving the problem are connected with the endemic character of biota and very diverse conditions of sedimentation in the basin. Regional subdivisions of the Eastern Paratethys are well substantiated based on benthic fauna studied in detail, primarily on mollusks and benthic foraminifers. Planktonic foraminifers, nannofossils, diatoms, and organic-walled phytoplankton have not been examined as thoroughly so far. In order to fill the gap in investigations, it is important to study planktonic and benthic macro- and microbiotas in the most complete uninterrupted Neogene sections of the region. In fact, many Neogene reference sections of southern Russia yield rich and diverse malacofauna that populated shallow shelf, whereas planktonic microflora inhabited deeper parts of the basin. Naturally, experts on malacofauna and planktonic groups paid principal attention to sediments bearing diverse polyhaline mollusks of the Tarkhanian and Konkian time, which dwelt in the basin, when it was connected with the World Ocean (Andreyeva-Grigorovich and Stupnitskii, 1976; Muzylev and Golovina, 1987; Lyul'eva, 1989; Il'ina, 1993, 2000; Andreyeva-Grigorovich and Savytskaya, 2000; Goncharova *et al.*, 2001, 2002; Krasheninnikov *et al.*, 2003). Our purpose was therefore to study jointly nannofossils and mollusks from a complete Chokrakian to lower Sarmatian succession of deep-water sediments and to elucidate peculiarities in evolution of both biotic groups during the Konkian. We chose sections of the Mt. Zelenskii anticline (Tamanskii Peninsula) and of the Pshekha River, Western Ciscaucasia (Fig. 1). The Konkian regional stage is poorly recognizable in both sections bearing impoverished molluscan assemblages. Nevertheless, Konkian sediments have been distinguished in the former section (Popov and Zastrozhnov, 1998) and apparently may present in the latter one.

Beginning from the terminal 19th century, both sections were studied by many researchers, and N.I. Andrusov was first among them. A detailed micropaleontological study was recently carried out in sections of the Tamanskii Peninsula and Ciscaucasia. During the medium-scale geological survey in Western Ciscaucasia that was initiated by the Federal State Unitary Geological Enterprise "Kavkazgeols'emka,"

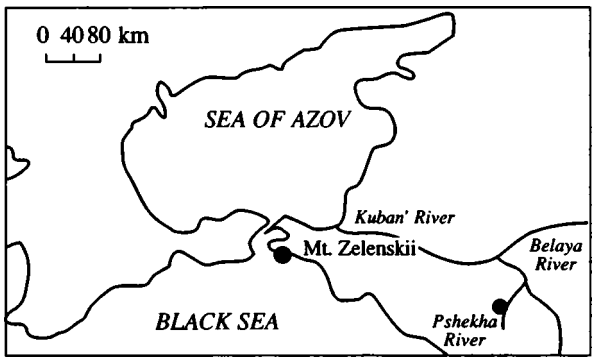


Fig. 1. Geographic localities of the studied sections.

Beluzhenko (2002a, 2002b) distinguished local formations of Neogene deposits. He considered the Pshekha River section as a stratotype of the Severoshirvanskaya (Tarkhanian–Chokrakian), Tsurevskii (Karaganian to mid-middle Sarmatian according to original definition), and Orlov Erik formations (middle Sarmatian).

TAMANSKII PENINSULA

The section of the Mt. Zelenskii anticline is one of the most complete Miocene sections of the Eastern Paratethys in Russia. The uninterrupted succession of the upper Chokrakian to Maeotian sediments is established in the northwestern flank of the anticline. Age of sediments exposed in the anticline core is debatable up to now. This is a consequence of their variable exposition controlled by active abrasion, intensity of which strongly changed in certain years. On the other hand, the relatively deep-water facies of the section yield impoverished malacofauna, and definition of regional stage boundaries is difficult therefore. This and other sections of the Tamanskii Peninsula were studied recently and described bed-by-bed by experts on lithology from the Department on Marine geology, Moscow State University, by micropaleontologists from the Geological Institute and by paleontologists from the Paleontological Institute, Russian Academy of Sciences, who will present soon a complete and precise lithological and biostratigraphic characteristics of the distinguished regional stages. We examined section of the Mt. Zelenskii anticline during field works of 1998–2002. Our particular attention was paid to deposits in the anticline core, which were previously variably dated within the broad Tarkhanian–Chokrakian interval, and to the Konkian–lower Sarmatian boundary interval, where Popov and Zastrozhnov (1998) distinguished and attributed to the base of the lower Sarmatian their Bed 6 (1 to 1.2 m thick) of light gray thin-bedded clay bearing abundant nannofossils. The detailed bed-by-bed examination showed that the following units are exposed in the study area (from the base upward; Fig. 2):

1. Bluish to violet gray clay, calcareous, very compact, finely banded, moire, with rare thin, sometimes lenticular, yellowish gray limestone laminae. Thin (2–5 cm) bituminous laminae smelling strongly present as well. In the middle of the unit, abundant fish remains (scale and bones) occur in association with tubes of polychaetes *Pectinaria lepidosa* Belokrys (=*?Pectinariopsis* sp. after Andrusov, 1916; Belokrys, 1967), which are composed of shells *Lutetia (Davidaschvilia) intermedia* (Bajar.). Transformation of *L. (D.) intermedia* into *Lutetia (Spaniodontella) gentilis* (Eichw.), which is characteristic of the late Chokrakian–Karaganian transitional interval, is recorded at a higher level, where shells *L. (D.) intermedia* become larger and their hinges slightly change as well (Zhgenti, 1999). For instance, small (2–4 mm) *L. (D.) intermedia* forms coexist in Sample 2 with a certain number of medium-sized (up to 5–6 mm) shells. In Sample 2-f and higher, at the base of the subsequent member, the medium-sized forms are more numerous, and large (up to 14 mm) *L. (S.) gentilis* shells characteristic of the Karaganian were encountered further upward. The unit is 15–17 m thick.

2. Rhythmical interbedding of greenish gray calcareous clay (2 to 3 m thick) and dolomitic limestone layers (14 to 25 cm thick). Upward up to the top, clay beds are less calcareous and darker in coloration, displaying abundant jarosite spots in places. Limestone layers are fractured by weathering into separate blocks. Lower limestone beds are compact and hard, whereas upper ones are chalklike, porous, readily effervescing with HCl. The Karaganian age of the sediments is defined based on species *Lutetia (Spaniodontella) gentilis* (Eichw.) found at the base of the unit that is 45–50 m thick in total.

3. Rhythmical alternation of clay and limestone layers grading upward into a more clayey interval of dark gray, slightly calcareous clay intercalated with rare and thin (3–5 cm) laminae of limestone and marl. The darker, almost black clay is fat, viscous, homogeneous, displaying shelly jointing and abundant jarosite spots along weathering fissures. At the unit top, there is again rhythmical alternation of clay and thin (1–5 cm) limestone layers, and these sediments yield abundant fish scale and bone remains. Popov and Zastrozhnov (1998) referred the unit to the Konkian. The total thickness is 18–20 m.

4. After unexposed interval about 3–5 m, there is a unit of dark gray to brownish clay more bedded closer to the top. Near the base, clay is thick-bedded, with slightly sandy bedding planes and white calcareous spots. Bedding is getting more distinct and frequent higher, where clay is greenish olive in coloration. Marine mollusks *Parvivenus konkensis* (Sok.) and *Mytilaster volhynicus* (Eichw.) were found in a thin (up to 1 cm) detrital layer 4 m below the top (Popov and Zastrozhnov, 1998). We found in this interval *Alveinus nitidus* (Reuss) and rarer *Ervilia pusilla trigonula* Sok. characteristic of the Konkian, which suggest the corre-

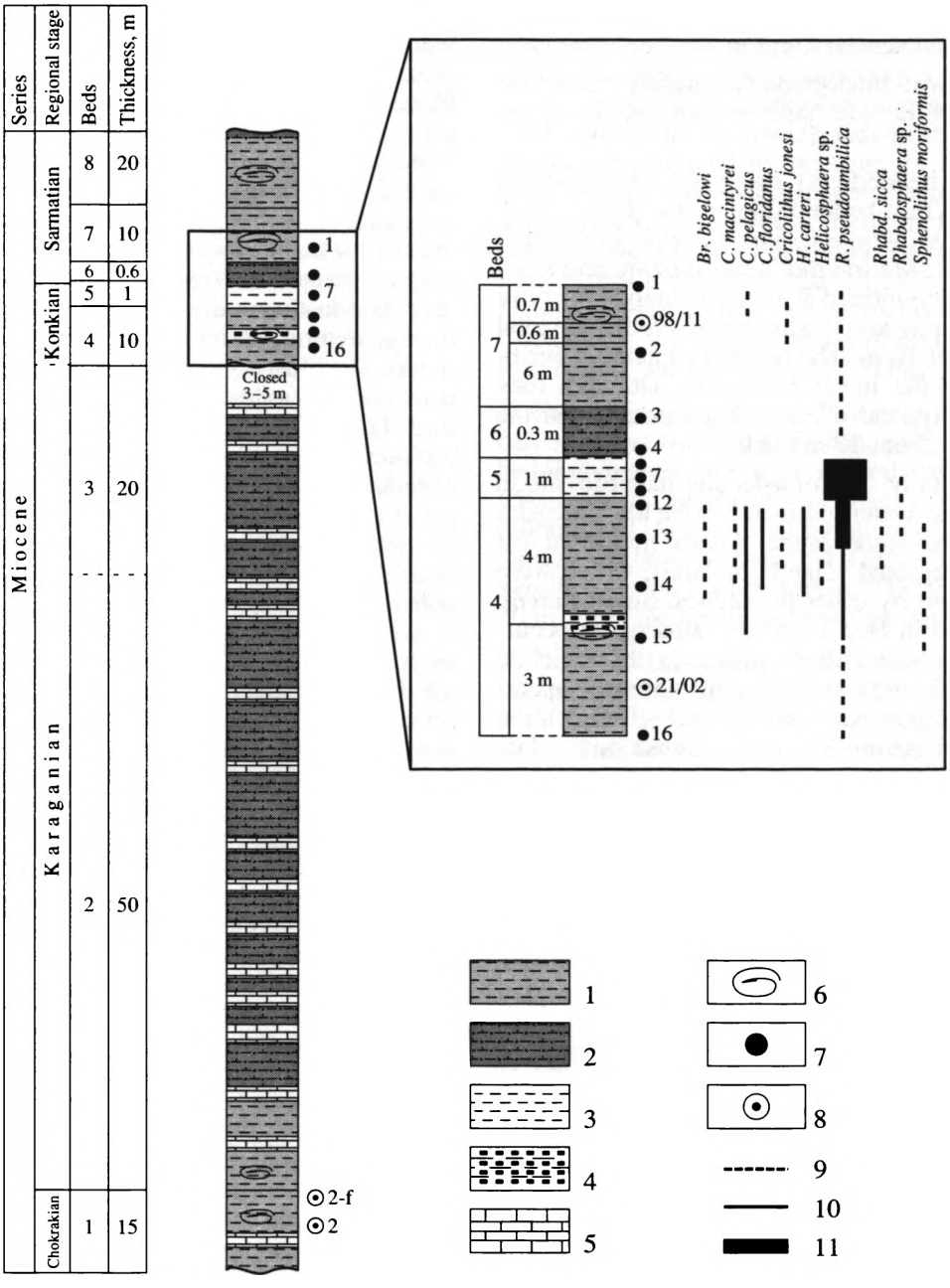


Fig. 2. Lithostratigraphy of the Middle Miocene sediments, the Mt. Zelenskii anticline: (1) calcareous, (2) carbonate-free, (3) calcareous thin-bedded nannofossil-bearing (marker bed) and (4) sandy clays; (5) limestone, marl; (6) mollusks; (7) samples with nannofossils; (8) samples with malacofauna; (9) rare, (10) common, (11) and abundant nannofossils.

sponding age to the unit. It is interesting that the Polychaeta tubes *Pectinaria* found in these sediments are composed at the early stages of *Alveinus* shells and, at the subsequent stage, of small broken gastropod shells, likely of spiratellas. The assemblage of marine fossils also includes *Modiolus* sp. and remains of a goby identified by E.K. Sychevskaya. The total thickness is 8–10 m.

5. Very fine alternation of greenish gray (brownish gray when weathered) clay and carbonate laminae (1 to 3 mm thick); the unit represents a distinct, light gray marker bed clearly seen even from the sea. As is established under scanning electron microscope, the thinnest white layers are composed of pure nannoplankton without terrigenous admixture, which is represented to monothetic *Reticulofenestra pseudoumbilica* assemblage. In the middle of the marker bed, clay laminae are virtually missing, and the interval corresponds to lenticular bed of very hard limestone almost lacking pores. The upper part of the unit again represents interbedding of clay and carbonate laminae. Popov and Zastrozhnov

(1998) referred the unit to the base of the lower Sarmatian. The total thickness is 1–1.2 m.

6. Dark brown, thick-bedded, slightly carbonate clay barren of fauna, with jarosite spots, about 60 cm thick.

7. Dark gray bedded clay enclosing a 60-cm-thick bed of less dark thin-bedded clay at the level of 6 m above the unit base, where sediments reveal foliation in a weathered state. Marine mollusks *Abra* sp. and *Musculus* sp. were encountered at approximately 4 m above the unit base (Popov and Zastrozhnov, 1998). The total thickness is about 10 m. The mentioned authors attributed the unit to the lower Sarmatian, although they found mollusks typical of the early Sarmatian in the overlying Unit 8 about 20 m thick.

A thorough study of mollusks and nannofossils in the relatively deep-water sediments of the Mt. Zelenskii anticline revealed some faunal trends important for revision of the regional stage boundaries, which were previously defined by other researches. Small *Lutetia intermedia* found in Bed 1 and the subsequent occurrence of medium-sized shells higher in the anticline section exemplify evolutionary steps toward appearance of *Lutetia (Spaniodontella) gentilis* (Eichw.), the species characteristic of the transitional late Chokrakian–Karaganian interval.

Popov and Zastrozhnov (1998) referred Bed 3 to the Konkian regional stage evidently based on the lithologic changes, as they identified fauna typical of the stage only in overlying sediments. We also failed to find either mollusks or nannofossils in that member, which corresponds in our opinion to the upper Karaganian level, actually to the Kartveli beds of deep-water deposits almost barren of fauna. This peculiarity of the Kartveli beds in Taman' area and some regions of western and central Ciscaucasia was noted first by Zhizhchenko (1940, 1959). However, Konkian deposits in other areas of the Tamanskii Peninsula "are represented by clay intercalated with occasional marl beds bearing echinoid remains, fragmented *Abra* shells, small spiratellas, and diverse benthic foraminifers. Their thickness is 10–15 m" (*Neogene System*, 1986, p. 145).

Popov and Zastrozhnov attributed their Bed 4 to the undivided Konkian–lower Sarmatian, but this unit should be referred to the Konkian as we believe. In addition to mollusks, Konkian age of respective sediments is consistent with occurrence of polyhaline foraminifers *Neobulimina* ex gr. *elongata* (Cusch.), *Articulina tenelia konkensis* Bogd., *Elphidium kudakoensis* Bogd., and *Nodobaculariella* sp. found in the member (Pinchuk, 1998). Sediments of Bed 4 also yielded a diverse (20 species) phytoplankton assemblage (Zaporozhets, 1998). Nannofossils were encountered first in Sample 16 from Bed 4, i.e., slightly lower than the first occurrence level of malacofauna. They are represented by scarce, very thin and fragile coccoliths *Reticulofenestra pseudoumbilica* Gartner. Higher and up to the top, nannofossils are more diverse, and their assemblage includes *Braarudosphaera bigelowi, Calcidiscus macintyrei, Coccolithus pelagicus, Cyclicargolithus floridanus, Cricolithus jonesi, Helicosphaera carteri, Helicosphaera* sp., *Reticulofenestra pseudoumbilica, Rhabdosphaera pannonica, Rhabdosphaera sicca, Rhabdosphaera* sp., and *Sphenolithus moriformis*. The assemblage is impoverished as compared to concurrent oceanic nannoplankton and lacks zonal species. We expect that further more thorough examination of stratigraphic range of *Helicosphaera* species, which are abundant in the studied samples, would be important for age determination of nannoplankton-bearing sediments. The most diverse assemblage of 10 to 12 species is recorded in a thin interval (1.5–3 m below the top of Bed 4), and then it rapidly becomes impoverished, replaced by the monothetic *Reticulofenestra pseudoumbilica* assemblage. Coccoliths *Reticulofenestra* are extremely abundant here, representing rock-forming components, which make up a marker bed 1 m thick (Bed 5). Abundance and preservation state of coccoliths are striking: we observed in mass the intact, perfectly preserved coccospheres under optical and scanning electron microscopes (Plate, figs. 1 and 3). Almost all the coccoliths *Reticulofenestra pseudoumbilica* retained their tracery delicate skeletons at proximal sides. A thorough examination of samples from the marker bed showed that *Reticulofenestra pseudoumbilica* sharply prevailing in the assemblage coexists with extremely scarce specimens of *Rhabdosphaera* sp. (Plate, figs. 10 and 11). The acme zone of described monothetic assemblage corresponds to the marker bed only (Bed 5). In the overlying dark gray, almost black clay of Bed 6, single semitransparent *Reticulofenestra pseudoumbilica* Gartner likely redeposited from the underlying sediments are recorded. Rare *Coccolithus pelagicus* and *Reticulofenestra pseudoumbilica* Gartner were encountered somewhat higher, 4 m above the top of the marker bed, where they occur in association with mollusks *Abra* sp. and *Musculus* sp. Scarce *Coccolithus pelagicus* and *Reticulofenestra pseudoumbilica* Gartner were also found in the basal part of the lower Sarmatian sediments.

The bed bearing diverse nannofossils in the Mt. Zelenskii section marks the most distinct marine phase in the basin evolution and concurrent appearance of the Konkian mollusks. Community of polychaetes *Pectinariopsis* and mollusks *Alveinus nitidus* (Reuss) is known so far from sediments of a deep shelf (lower subtidal zone). *Modiolus* species prefer to dwell in deep waters as well. At the same time, *Parvivenus* and *Mytilaster* (single) forms, species *Ervilia pusilla trigonula* (more numerous), and remains of goby represent a community of shoals or upper subtidal zone. Many shells of mollusks are unsatisfactory preserved, as they are rounded and frayed at their surface. The molluscan assemblage is evidently of a composite type, composed of buried *in situ* and redeposited shells. A part of mollusks and remains of goby were most likely transported the burial site from shoals immediately steeping down

to the relatively deep lower subtidal zone. Dwarfed mollusks of impoverished taxonomic composition and rare occurrence of their shells indicate unfavorable habitat conditions in shallow zone, which evidently experienced the freshening effect of rivers and hydrodynamic impacts. According to composition of mollusks, salinity in the basin was somewhat lower than normal, though not less than 20‰. The decreased salinity of seawater is also evident from composition of the nannofossil assemblage that is lacking zonal and many other oceanic species, thus being of an impoverished type. The upward transition from the relatively diverse nannofossils to their monothetic assemblage likely reflects a rapid turn of bionomic conditions in the respective part of the basin. The basin part under discussion evidently corresponded to a zone that separated freshened and more saline waters. That zone was rich in nutrients, favorable for a mass development of most tolerant nannoplankton species, which turned into rock-forming biogenic components. Radionova who examined diatoms from clayey laminae showed that frequent intercalation of carbonate and clay laminae is associated with alternate domination of different planktonic groups (Golovina and Radionova, 2003). Especially significant are few specimens of *Cymatosyra biharensis* found in studied sediments, because this species is widespread in Sarmatian deposits. Thus, Bed 5 can be regarded as a unit transitional from Konkian to Sarmatian sediments. On the one hand, we observe here replacement of relatively diverse nannofossils by their monothetic assemblage that is indicative of a terminal stage in development of the Konkian assemblages, and on the other hand, typical Sarmatian taxon appears among diatoms characterizing the bed.

WESTERN CISCAUCASIA

The Pshekha River section is one of the most complete Miocene sections of the Eastern Paratethys in Russia. It is located in the Afips-Pshekha structural-facies subzone of the West Caucasian zone within the Psekups–Pshekha–Kurdzhips interfluve area. In recent years, Beluzhenko (2002a) thoroughly studied and described the relatively deep-water sediments of the upper Chokrakian, Karaganian, and Sarmatian, which are exposed to a variable extent near the Tsurevskii Village. In 1999–2000, we examined together with her mollusks and nannofossils found respectively in the Tarkhanian–Maeotian and Karaganian–lower Sarmatian intervals. The section description presented below is after Beluzhenko with our additions. Mollusks and nannofossils were studied in the samples collected on both the right and left banks of the Pshekha River, beginning from the level of fauna-bearing Karaganian sediments.

The lower Tsurevskii Subformation overlies noncalcareous barren clay of the Maikop type. This subdivision is composed of dark gray to black calcareous clays intercalated with marl beds from 0.1 to 0.4 m thick. Only two levels with molluscan shells are detected in the unit. The first one is in the lower part of Bed 2 that yields small (dominant) and medium-sized shells *Lutetia (Davidaschvilia) intermedia.* The second level with mollusks corresponds to the base of Bed 5 and is characterized by presence of mainly medium-sized *Lutetia* forms and scarce *Ervilia* sp. The lower Tsurevskii Subformation is 95 m thick. It is quite possible that Beds 6–9 of the middle Tsurevskii Subformation, except for Bed 10 marked by first occurrence of *Spaniodontella* forms, can be also referred to the late Chokrakian. We began to study of mollusks and nannofossils since the level of Bed 10 (Fig. 3).

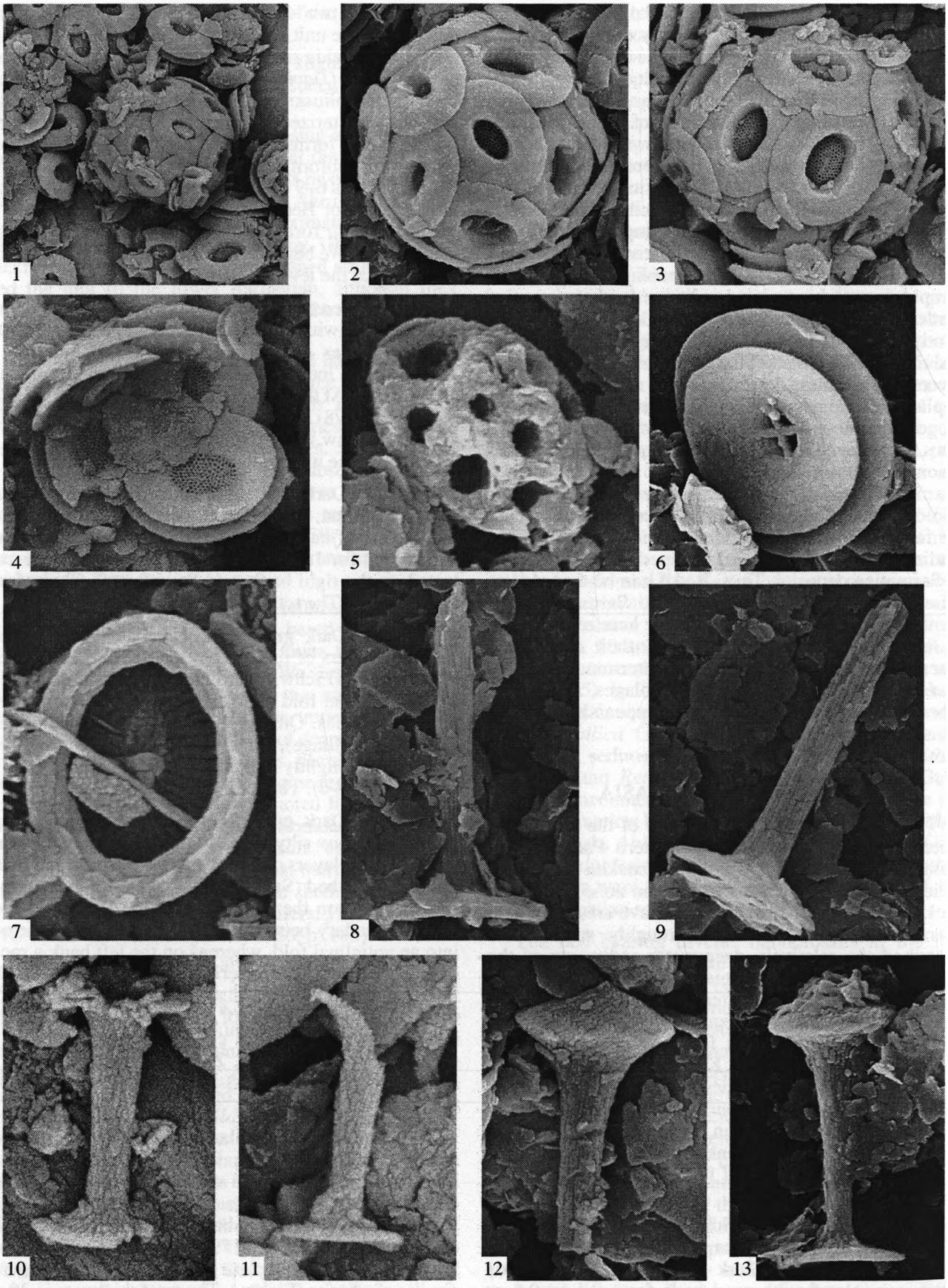
Bed 10 is composed of dark gray, thin-bedded, calcareous clays with films of micaceous aleurite along the bedding planes and with several (up to four) 5- to 15–cm-thick interlayers of flaggy marl commonly dolomitized. At the initial sampling point (Sample 50 = Sample 2178/8) thin-walled *Lutetia (Spaniodontella) gentilis* (Eichw.) were found. The total thickness is 30 m. Only the upper eight meters were sampled.

Bed 11. Dark gray, thin-bedded, calcareous clay barren of fauna; in the lower part clay is intercalated with layers of hard dolomitized marl (0.1–0.3 m thick and spaced for 1.5 to 4 m). Samples 54–58a were collected on the right bank, and Samples 60–63 are from the left bank. The total thickness is 20 m.

Bed 12. Dark gray, thin-bedded, calcareous clay with interlayers of hard flaggy marl. Numerous shells *Abra reflexa* (Eichw.) were encountered in clays of a small anticlinal fold exposed on the right bank (Samples 66 and 68). On the left bank (a scarp below the Tsurevskii Village), first shells *Abra reflexa* were encountered slightly higher, in the upper part of Bed 12 (Sample 2179-6). The total thickness is 11 m.

Bed 13. Dark gray, thin-bedded, calcareous clay with micaceous silty films along bedding planes and with two interlayers of flaggy marl at the base and in the middle of the bed (Samples 69–74). We sampled exposures mainly on the right bank of the Pshekha River, where boundary between Beds 12 and 13 is deformed into an anticlinal fold, whereas on the left bank a monoclinal dipping is characteristic of sediments. In 2002, Popov and Rostovtseva discovered on the left bank a 0.8- to 1.2-m-thick layer of frequently alternating dark and light gray calcareous clays analogous to those of the marker bed in the Mt. Zelenskii section. In Fig. 3, this layer is marked as 13-f within Bed 13. The total thickness is 13–24.5 m.

Bed 14. Dark gray to black, thin-bedded, partly foliated and calcareous clay with micaceous silty films along bedding planes and with inclusions of coalified organic remains and fish scale. Lenticular interlayers of hard marl are confined to basal portion of the bed. The overlying clay (Sample 2179-9) yields the early Sarmatian mollusks *Abra reflexa* (Eichw.), *Mactra* sp., and *Ervilia* cf. *dissita* (Eichw.). The total thickness is 30 m.


1
2
3
4
5
6
7
8
9
10
11
12
13

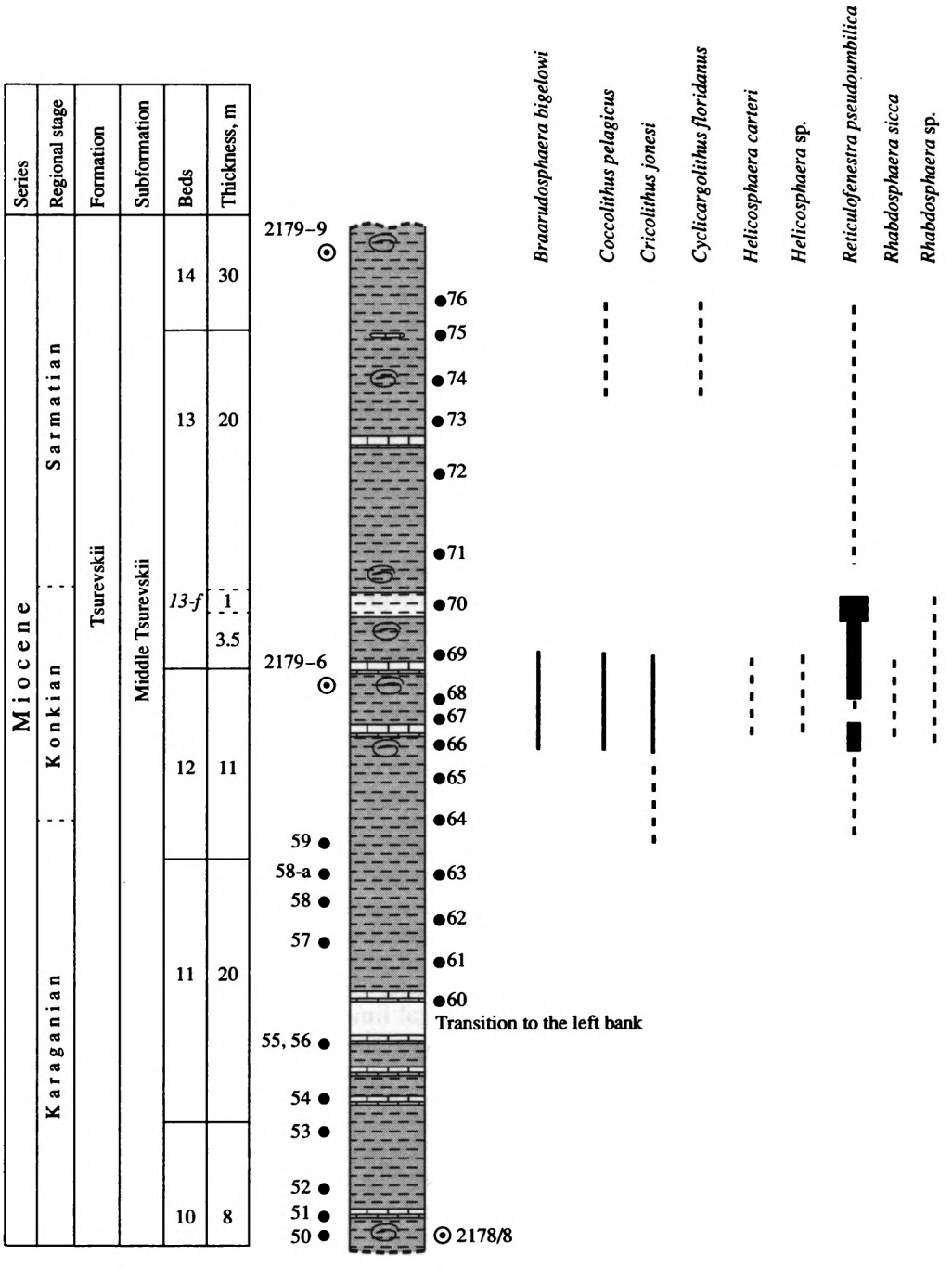


Fig. 3. Lithostratigraphy of Middle Miocene sediments, the Pshekha River section (symbols as in Fig. 2).

Nannofossils from the Konkian deposits of the Tamanskii Peninsula and Western Ciscaucasia.

(1) General view of sediment from the marker bed, section of the Mt. Zelenskii anticline, Tamanskii Peninsula, Sample 7, ×7500. (2) Coccosphere *Reticulofenestra pseudoumbilica* Gartner, marker bed in the Pshekha River section, ×15000. (3) Coccosphere *Reticulofenestra pseudoumbilica* Gartner, marker bed in the Mt. Zelenskii section, Tamanskii Peninsula, Sample 7, ×15000. (4) Fragment of coccosphere *Reticulofenestra pseudoumbilica* Gartner, marker bed in the Mt. Zelenskii section, Tamanskii Peninsula, Sample 7, ×15000. (5) *Holodiscus macroporus* (Deflandre) Roth from the Pshekha River section, Sample 66, ×30000. (6) *Cruciplacolithus tenuiforatus* Clocchiatti, Jerkovic from the Pshekha River section, Sample 66, ×22500. (7) *Syracosphaera* sp. from the Pshekha River section, Sample 66, ×30000. (8, 9) *Rhabdosphaera* sp. from the Pshekha River section, Sample 66, ×22500. (10, 11) *Rhabdosphaera* sp. from marker bed in the Mt. Zelenskii section, Tamanskii Peninsula, Sample 7, ×22500. (12, 13) *Rhabdosphaera* sp. from the Pshekha River section, Sample 66, ×22500.

The section interval from the Bed 10 base to the Bed 11 top (Samples 50–63) bears abundant though redeposited Paleogene and Cretaceous nannofossils. The undeniably autochthonous nannoplankton was found first in Sample 64 of the clay identical in lithology to that sampled previously. In the upper part of Bed 12 and at the base of Bed 13 (Samples 66–69), we identified *Braarudosphaera bigelowi, Coccolithus pelagicus, Cricolithus jonesi, Cruciplacolithus tenuiforatus*, abundant *Reticulofenestra pseudoumbilica, Rhabdosphaera sicca*, rare specific *Rhabdosphaera* sp. (Plate, figs. 12 and 13), *Helicosphaera carteri, Helicosphaera* sp., *Holodiscus macroporus*, and *Syracosphaera* sp. Host sediments of these fossils also yield foraminifers *Discorbis cartvelicus, D. effusus, Nonion* aff. *granosus, Elphidium* aff. *incertum*, and *Bulimina* sp. (Krasheninnikov *et al.*, 2003). *Abra reflexa* (Eichw.) was also found first in this interval of the section, and this species first appearing in the Konkian suggest the corresponding age to the section interval. In the lower part of Bed 13 (Sample 70), the nannofossil species listed above are replaced by monothetic *Reticulofenestra pseudoumbilica* assemblage. The coccoliths are extraordinary abundant, lacking terrigenous admixture within a separate marker bed of sediments, which is 1 to 1.2 m thick and corresponds to acme zone of taxon. Three meters above (Sample 71), we found only few specimens of *Reticulofenestra pseudoumbilica.* Samples 72 and 73 yielded mainly redeposited Cretaceous and Paleogene species and very scarce, poorly preserved coccoliths. A few *Coccolithus pelagicus, Cyclicargolithus floridanus*, and *Reticulofenestra pseudoumbilica* occur in association with redeposited forms in Samples 75 and 76. The interval bearing nannoplankton is about 10 m thick in total, whereas the horizon bearing monothetic assemblage is approximately 1 to 1.2 m thick like in the Tamanskii Peninsula. The development trend of nannofossils is like that described above in the Mt. Zelenskii section: the lower impoverished nannoplankton is rapidly replaced by the monothetic assemblage constituting the marker bed. The first occurrence of nannofossils almost coincides with the first occurrence level of the *Abra reflexa* and *Alveinus nitidus* (Reuss), which undoubtedly confirm recognition of the Konkian stage in the section. The early Sarmatian fauna appears 20 m above the marker Bed 14. At the same level, numerous leaf imprints and remains of brown alga thalluses (genus *Sargassum*) are recorded (identified by M.A. Akhmet'ev). We emphasize that age of the lower Tsurevskii Subformation and lowermost middle Tsurevskii strata should be changed based on the studied malacofauna and lithology. In our subdivision scheme of the Chokrakian and Karaganian sediments, the transitional interval, where inherited development of *Lutetia (Spaniodontella) gentilis* from *Lutetia (Davidaschvilia) intermedia* is recorded, corresponds to the late Chokrakian, and therefore the lower Tsurevskii Subformation and likely lowermost strata of the Middle Tsurevskii Subformation, should be the late Chokrakian in age.

CONCLUSIONS

The lithologic and biostratigraphic results obtained imply that relatively deep-water successions of the Tamanskii Peninsula and Western Ciscaucasia are similar in lithology and biostratigraphy within the upper Chokrakian–middle Sarmatian interval. In the terminal Chokrakian time, water circulation in deep areas of sea basin was disturbed: the warm freshened waters appeared above the colder, likely more saline water layer. This resulted in development of stagnant conditions favorable for accumulation of black clays free of carbonate. Simultaneously, shoals above submarine rises (flanks of the basin) were suitable the mass development of stromatolites, which replaced the bryozoan bioherms. Accumulation of calcareous clay members enclosing stromatolite buildups was associated with this stage in the basin evolution. In the Tamanskii Peninsula, the upper Chokrakian interval is represented by dark gray to black clay lacking carbonate material, whereas in Western Ciscaucasia, concurrent dark gray to black clays without carbonates are intercalated with beds of light gray calcareous clay enclosing nodular stromatolites.

In the Karaganian, accumulation of sediment was stable for a considerably long time. Thick sequences of carbonate-free and slightly calcareous clays accumulated in that period. Respective sediments are rich in pyrite, plant detritus, and organic matter, bearing an insignificant terrigenous admixture (quartz, feldspar, mica, and single redeposited glauconite grains). Fine-grained peloidal (cyanobiontic) limestones accumulated periodically. Parallel to clay accumulation in the deeper parts of the basin, vigorous accumulation of algal limestones was characteristic of shallow settings and probably of the entire euphotic zone of the basin. In the Tamanskii Peninsula, the Karaganian sediments enclose carbonate beds with current and drift marks indicative of redeposition. The limestone strata yield ostracodes, fish remains, and algae impressions. In the Pshekha River section, the Karaganian interval is composed mostly of clay with rare interlayers of peloidal limestones. In the late Karaganian, hydrologic regime in the basin gradually changed owing to commencement of transgression. The transgression maximum was in the Konkian time, when slightly and more calcareous clays with marine macro- and microfauna accumulated. In the early Sarmatian, sedimentation gradually stabilized. In the Pshekha River section, basal clay members of the lower Sarmatian bear abundant organic matter, leaf impressions, algae thalluses and detritus.

The studied mollusks imply that sediments in the core of the Mt. Zelenskii anticline are the late Chokrakian in age. Phylogeny of *Spaniodontella gentilis* (Eichw.) is distinctly recorded in the transitional late Chokrakian–Karaganian interval of sections both in the

Tamanskii Peninsula and Western Ciscaucasia. The joint study of mollusks and nannofossils in both regions showed that Konkian sediments bear nannofossils, which are impoverished as compared to typical oceanic assemblages, while the abundance zone of monothetic *Reticulofenestra pseudoumbilica* assemblage is confined to the Konkian–Sarmatian boundary beds. Salinity in the basin was lowered down to 20‰, as is estimated based on benthic mollusks, and taxonomic composition of dinocysts is indicative of oxygen deficiency in bottom waters (Zaporozhets, 1998). Planktonic fossils (nannoplankton and dinocysts) suggest a rapid salinity decrease in the basin. Flourishing of *Reticulofenestra pseudoumbilica* most likely took place in a frontal contact zone between river and marine waters or in the past upwelling zone. Thus, the terminal Konkian time corresponded to peculiar bionomic conditions in the study region. The Konkian upper boundary is defined at the top of the marker bed deposited at the time of *Reticulofenestra pseudoumbilica* flourishing. The Konkian base should be placed in our opinion at the first occurrence level of polyhaline benthos or plankton in the deep-water facies. During field work, the first occurrence level of *Abra reflexa* can be regarded as indication of the Konkian level in deep-water sediments barren of other mollusks. This is consistent with conclusions of Zhizhchenko (1959) and Buryak (1960) who suggested that lower beds of sediments bearing *Abra reflexa* only can be attributed to the Konkian.

The results of current paleontological and lithological investigations elucidate some principal events in evolution of the studied paleobasin. They are important for revision and determination of certain boundaries between local formations and subformations, and for their correlation with regional stages.

ACKNOWLEDGMENTS

We are grateful to E.V. Beluzhenko (FSUGE "Kavkazgeols"emka"), S.V. Popov (Paleontological Institute RAS), and N.V. Gor'kova (Geological Institute RAS) for their help in the work, donated samples, and study of nannofossils under scanning electron microscope. The work was supported by the Russian Foundation for Basic Research, project no. 01-05-64424 and by the FCP "Integration," project no. 30198/671.

Reviewers N.Yu. Filippova and M.A. Akhmet'ev

REFERENCES

1. A. S. Andreyeva-Grigorovich and V. M. Stupnitskii, "Lower Miocene Nannofossils from the Southeastern Cis-Carpathian region," Geol. Zh. AN USSR. Otd. Nauk o Zemle. **36** (1), 139–142 (1976).
2. A. S. Andreyeva-Grigorovich and N. A. Savytskaya, "Nannoplankton of the Tarkhanian Deposits of the Kerch Peninsula (Crimea)," Geol. Carpathica **51** (6), 399–406 (2000).
3. L. S. Belokrys, "On Sarmatian Pectinariids," Paleontol. Zh. **2**, 129–134 (1967).
4. E. V. Beluzhenko, "Middle-Upper Miocene and Pliocene Stratigraphy of the Psekups–Belaya Interfluve (Northwestern Caucasus), Pt. 1: Middle Miocene," Byull. Mosk. O–va Ispyt. Prir. Otd. Geol. **77** (1), 47–59 (2002a).
5. E. V. Beluzhenko, "Middle-Upper Miocene and Pliocene Stratigraphy of the Psekups–Belaya Interfluve (Northwestern Caucasus), Pt. 2: Upper Miocene and Pliocene," Byull. Mosk. O–va Ispyt. Prir. Otd. Geol. **77** (2), 51–62 (2002b).
6. V. N. Buryak, "Miocene Sediments of the Eastern Kuban," Tr. Krasnodar. Fil. Vses. Neftegaz. Nauchno-Issled. Inst. **3**, 67–81 (1960).
7. L. A. Golovina and E. P. Radionova, "Monothetic Nannoplankton and Diatom Assemblages in the Middle–Upper Miocene Sediments of the Eastern Paratethys," in *Proceedings of the 12th Workshop on Radiolarians: Modern Problems of Geology* (Nauchnyi Mir, Moscow, 2003), p. 322 [in Russian].
8. I. A. Goncharova, S. O. Khondkarian, and I. G. Shcherba, "Tarkhanian–Karaganian Stage in Development of the Euxinian–Caspian Basin (Eastern Paratethys). Part 1. Tarkhanian," Stratigr. Geol. Korrelyatsiya **9** (5), 94–108 (2001) [Stratigr. Geol. Correlation **9**, 508–522 (2001)].
9. I. A. Goncharova, S. O. Khondkarian, and I. G. Shcherba, "Tarkhanian–Karaganian Stage of Development of the Euxinian–Caspian Basin (Eastern Paratethys). Part 2," Stratigr. Geol. Korrelyatsiya **10** (2), 100 (2002) [Stratigr. Geol. Correlation **10**, 196–208 (2002)].
10. L. B. Il'ina, *Atlas of Middle Miocene Marine Gastropods of Southwestern Eurasia* (Nauka, Moscow, 1993) [in Russian].
11. L. B. Il'ina, "On the Regional Konkian Stage (Middle Miocene) in the Eastern Paratethys," Stratigr. Geol. Korrelyatsiya **8** (4), 59–64 (2000) [Stratigr. Geol. Correlation **8**, 372–377 (2000)].
12. V. A. Krasheninnikov, I. A. Basov, and L. A. Golovina, *Tarkhanian and Konkian Regional Stages of the Eastern Paratethys (Stratigraphy, Micropaleontology, Bionomy, Paleogeographic Connections)* (Nauchnyi Mir, Moscow, 2003) [in Russian].
13. S. A. Lyul'eva, "Miocene and Pliocene Ceratoliths (Nannofossils) of Southwestern USSR," Dokl. Akad. Nauk Ukr. SSR, Ser. B. Geol., Khim., Biol. No. 11, 14–18 (1989).
14. N. G. Muzylev and L. A. Golovina, "On Connection of the Ponto-Caspian and World Ocean in the Early–Middle Miocene (Tarkhanian–Sarmatian)," Izv. Akad. Nauk SSSR, Ser. Geol. No.12, 62–72 (1987).
15. *Neogene System, Vol. 1, Stratigraphy of the USSR*. Ed. by M. V. Muratov and L. A. Nevesskaya (Nedra, Moscow, 1986) [in Russian].
16. T. N. Pinchuk, "Foraminifers from the Tamanskii Peninsula," in *Neogene Reference Sections of the Eastern*

Paratethys (Tamanskii Peninsula), (Volgogr. Geol.-Razved. Eksped., Volgograd, 1998), pp. 26–30 [in Russian].

17. S. V. Popov and A. S. Zastrozhnov, *Neogene Reference Sections of the Eastern Paratethys (Tamanskii Peninsula). Excursion Guide. Volgograd–Taman'* (Volgogr. Geol.-Razved. Eksped., Volgograd, 1998) [in Russian].
18. N. I. Zaporozhets, "Lower and Middle Miocene Organic-Walled Phytoplankton of the Eastern Paratethys," in *Neogene Reference Sections of the Eastern Paratethys (Tamanskii Peninsula)* (Volgogr. Geol.-Razved. Eksped., Volgograd, 1998), pp. 31–37 [in Russian].
19. E. M. Zhgenti, "On the Neoteny Phenomenon in the Evolution of the Superfamily Veneracea," in *Problems of Paleobiology, Vol. 1. in Memory of L. Sh. Davitashvili* (Metsniereba, Tbilisi, 1999), pp. 144–160 [in Russian].
20. B. P. Zhizhchenko, "Lower and Middle Miocene," in *Stratigraphy of the USSR. Neogene* (Akad. Nauk SSSR, Moscow, 1940), Vol. 12, pp. 11–227 [in Russian].
21. B. P. Zhizhchenko, *Atlas of the Middle Miocene Fauna from the Northern Caucasus and Crimea* (Gosnauchtekhizdat, Moscow, 1959) [in Russian].

Stratigraphy and Geological Correlation, Vol. 12, No. 6, 2004, pp. 647–649.

Author Index to Volume 12, 2004

Akhmet'ev, M.A., Aleksandrova, G.N., Beniamovskii, V.N., Vitukhin, D.I., Glezer, Z.I., Gnibidenko, Z.N., Dergachev, V.D., Dolya, Zh.A., Zaporozhets, N.I., Kozlova, G.E., Kul'kova, I.A., Nikolaeva, I.A., Ovechkina, M.N., Radionova, E.P., and Strel'nikova, N.I., New Data on the Marine Paleogene of the Southern West Siberian Plate, Paper 2	5	495–513
Akhmet'ev, M.A., Aleksandrova, G.N., Beniamovskii, V.N., Vitukhin, D.I., Glezer, Z.I., Gnibidenko, Z.N., Dergachev, V.D., Dolya, Zh.A., Zaporozhets, N.I., Kozlova, G.E., Kul'kova, I.A., Nikolaeva, I.A., Ovechkina, M.N., Radionova, E.P., and Strel'nikova, N.I., New Data on the Marine Paleogene of the Southwestern Siberian Plate, Paper 1	1	58–84
Akhmet'ev, M.A., Zaporozhets, N.I., and Makulbekov, N.M., The Eocene Fossil Plants, Spores, Pollen, and Dinocysts from the Tavda Formation, the Pavlodar Area near the Irtysh River	2	167–174
Akulov, N.I., Devonian Paleogeography and Sedimentation Settings in the South Siberian Platform	3	241–252
Arkad'ev, V.V. and Bogdanova, T.N., Genus *Berriasella* (Ammonoidea) and Ammonoid Zonation in the Berriasian of the Crimean Mountains	4	367–379
Bezrodnykh, Yu.P., Romanyuk, B.F., Deliya, S.V., Magomedov, R.D., Sorokin, V.M., Parunin, O.B., and Babak, E.V., Biostratigraphy and Structure of the Upper Quaternary Deposits and Some Paleogeographic Features of the North Caspian Region	1	102–111
Bragina, L.G. and Bragin, N.Yu., Radiolarians from Upper Cretaceous Deposits, the Novodevich'e Section (Samara Oblast, Volga River Middle Courses)	3	286–296
Bylinskaya, M.E. and Golovina, L.A., Correlation of the Pliocene–Quaternary Foraminiferal and Nannofossil Zonations in the North Atlantic	3	309–319
Chashchin, V.V., Bayanova, T.B., and Levkovich, N.V., The Kislaya Guba Formation of the Late Archean Terskii–Allarechensk Greenstone Belt (Kola Peninsula, Russia): Stratotype and U–Pb Age	6	541–552
Chumakov, N.M., Trends in Global Climate Changes Inferred from Geological Data	2	117–138
Devyatkin, E.V., Geochronology of Cenozoic Basalts in Mongolia and Their Relationships with Neotectonic Structures	2	199–209
Ermakova, S.P., On the Upper Induan and Lower Olenekian Substages of the Boreal Realm (Critical Comments to Article by Yu.D. Zakharov and Co-authors)	5	534–537
Gladenkov, A.Yu. and Gladenkov, Yu.B., Onset of Connections between the Pacific and Arctic Oceans through the Bering Strait in the Neogene	2	175–187
Gladenkov, Yu.B., Some Problems and Main Orientating Points of Stratigraphy in the Early XXI Century	4	331–335
Golovina, L.A., Goncharova, I.A., and Rostovtseva, Yu.V., New Data on the Middle Miocene Biostratigraphy (Nannofossils, Mollusks) and Lithology of the Tamanskii Peninsula and Western Ciscaucasia	6	637–646
Herman, A.B., Moiseeva, M.G., Spicer, R.A., and Ahlberg, A., Maastrichtian–Paleocene Floras of Northeastern Russia and North Alaska and Floral Changes at the Cretaceous–Paleogene Boundary	5	485–494
Herman, A.B., The Cretaceous Flora of the Kuk-Kaolak Area, Northern Alaska	4	380–393
Kabanov, P.B., Serpukhovian Stage Stratotype in Zaborje Quarry (Moscow Region). Part II. Subaerial Exposure Profiles and Cyclicity	3	253–261
Kiselev, D.N., The Thermal Regime Dynamics in Callovian–Oxfordian Seas of Northwestern Eurasia: Implications of Relative Paleotemperature Data	4	347–366

© 2004 MAIK "Nauka/Interperiodica"

Kotlyar, G.V., Kossovaya, O.L., Shishlov, S.B., Zhuravlev, A.V., and Pukhonto, S.K., Boundary between Permian Series in Diverse Sedimentary Facies of North European Russia: Constraints of Event Stratigraphy 5 460–484

Kuz'min, Ya.V., Critical Remarks to the Paper by S.A. Laukhin, A. Ronen, V.A. Ranov, G.A. Pospelova, Ya.M. Burdukevich, Z.V. Sharonova, V.A. Volgina, O.A. Kulikov, V.K. Vlasov, and A. Tsatskin *New Data on the Paleolithic Geochronology in Southern Levant* 2 217–218

Laukhin, S.A., Reply to the Critical Review by Ya.V. Kuz'min 2 219–220

Lebedev, V.A., Chernyshev, I.V., Arakelyants, M.M., Gol'tsman, Yu.V., Dudauri, O.Z., and Vashakidze, G.T., Geochronology of the Neogene–Quaternary Dacitic Volcanism in the Northwestern Lesser Caucasus (Georgia) 1 85–101

Leven, E.Ja. and Ozkan, R., New Permian Fusulinids from Turkey and Some Problems of Their Biogeography 4 336–346

Leven, E.Ja., Fusulinids and Permian Scale of the Tethys 2 139–151

Makulbekov, N.M., Stratigraphic Position of the Albian and Late Cretaceous Floras in Southern Mongolia 6 588–602

Mizens, G.A., Chernykh, V.V., and Mizens, L.I., Correlation of Frasnian–Famennian Boundary Deposits in Western Regions of the Magnitogorsk Megazone (Eastern Flank of Southern Urals) 1 22–34

Ochev, V.G., Shishkin, M.A., Kukhtinov, D.A., Tverdokhlebov, V.P., and Makarova, I.S., Some Unsolved Problems of Triassic Stratigraphy in Eastern Europe 3 262–274

Olfer'ev, A.G., Alekseev, A.S., Beniamovskii, V.N., Vishnevskaya, V.S., Ivanov, A.V., Pervushov, E.M., Sel'tser, V.B., Kharitonov, V.M., and Shcherbinina, E.A., The Mezino-Lapshinovka Reference Section of the Upper Cretaceous and Problems of Santonian–Campanian Boundary in Saratov Area near the Volga River 6 603–636

Pevzner, M.A., Semenenko, V.N., Vangengeim, E.A., Sadchikova, T.A., Kovalenko, V.A., and Lyul'eva, S.A., On the Marine Genesis and Pontian Age of Deposits from the Lyubimovka Reference Section in the Crimea 5 523–533

Podgainaya, N.N., Evolution of Phanerozoic Miospores and Main Striation Types 3 229–240

Rogov, M.A., Ammonite-Based Correlation of the Lower and Middle (*Panderi* Zone) Volgian Substages with the Tithonian Stage 1 35–57

Sal'nikova, E.B., Larin, A.M., Kotov, A.B., Glebovitskiœ, V.A., Sukhanov, M.K., Yakovleva, S.Z., Kovach, V.P., Berezhnaya, N.G., and Tolkachev, M.D., The Kalar Anorthosite–Charnokite Complex of the Aldan–Stanovoi Shield: Age and Tectonic Implications 3 221–228

Semikhatov, M.A., Kuznetsov, A.B., Podkovyrov, V.N., Bartley, J.K., and Davydov, Yu.V., The Yudoma Group of Stratotype Area: C-isotope Chemostratigraphic Correlations and Yudomian–Vendian Relation 5 435–459

Sergeev, V.N. and Lee Seong-Joo, New Data on Silicified Microfossils from the Satka Formation of the Lower Riphean Stratotype, the Urals 1 1–21

Serova, M.Ya., The Lower Paleocene of the Kronotskii Peninsula, Eastern Kamchatka 5 514–522

Shantser, A.E. and Chelebaeva, A.I., Stratigraphy, Geological Events, and a New Model of Late Cretaceous–Early Paleogene Rifting in Central Kamchatka 4 394–405

Shapiro, M.N., Solov'ev, A.V., Garver, G.I., Shcherbinina, E.A., Ledneva, G.V., and Brandon, M.T., Age of Terrigenous Rocks of Northeastern Karaginskiĭ Island (Eastern Kamchatka) 2 188–198

Sklyarov, Yu.A., On the Galactic Version of Geochronological Scale 4 425–432

Smirnova, T.N. and Baraboshkin, E.Yu., Valanginian–Lower Hauterivian Brachiopod Assemblages from the Kacha–Bodrak Interfluve, Southwestern Crimea 2 152–166

Soloviev, A.V., Hourigan, J.K., Brandon, M.T., Garver, J.I., and Grigorenko, E.S., The Age of the Baraba Formation Inferred from the U/Pb (SHRIMP) Dating (Sredinnyi Range, Kamchatka): Geological Consequences 4 418–424

Sorokin, A.A., Ponomarchuk, V.A., Sorokin, A.P., and Kozyrev, S.K., Geochronology and Correlation of Mesozoic Magmatic Complexes in the Northern Margin of the Amurian Superterrane 6 572–587

Stupin, S.I., Foraminifers and Depositional Environments of Upper Paleocene Sediments in the Northeastern Peri-Tethys 3 297–308

Vasil'ev, A.N., Biogeochemical Study of Lower Sarmatian Bivalves from the Southern Margin of the Ukrainian Shield and Their Stratigraphic Significance 2 210–216

Veis, A.F., Fedorov, D.L., Kuzmenko, Yu.T., Vorob'eva, N.G., and Golubkova, E.Yu., Microfossils and Riphean Stratigraphy in the North European Platform (Mezen Syneclise) 6 553–571

Yaroshenko, O.P. and Lozovsky, V.R., Palynological Assemblages of Continental Lower Triassic in Eastern Europe and Their Interregional Correlation. Paper 1: Palynological Assemblages of the Induan Stage 3 275–285

Zakharov, Yu.D., To the Problem of the Induan–Olenekian Boundary (Response to the Critical Comments of S. P. Ermakova) 5 538–539

Zhamoida, A.I., Problems Related to the International (Standard) Stratigraphic Scale and Its Perfection 4 321–330

Zharov, A.E., Gal'versen, V.G., Serova, M.Ya., and Fot'yanova, L.I., The Tunaicha Formation and Its Age Analogues, Southern Sakhalin 4 406–417

Ninetieth Birthday of Academician Boris Sergeevich Sokolov 1 113

Viktor Efimovich Khain (on 90th Birthday) 3 320

In Memory of Nikita Alekseevich Bogdanov (1931–2003) 4 433

GEOLOGY OF ORE DEPOSITS
(Geologiya rudnykh mestorozhdenii)

Editor-in-Chief
Nikolai P. Laverov
Member of the Russian Academy of Sciences, Professor, Director of the Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, RAS, Moscow, Russia

Geology of Ore Deposits is one of the few special journals devoted to metallic and nonmetallic mineral resources and the conditions of their formation and distribution. Founded in 1959, the journal contains original scientific articles and reviews on a wide range of problems in theoretical and applied science. From 2001 on, the journal will be focused on the following problems: geology and setting of metallic deposits, geology and setting of nonmetallic deposits, physicochemical parameters of ore-forming processes, evolution of ore-forming systems, deep structure of the Earth and ore formation, global correlation of metallogenic zones and deposits, radiogeology and radiogeoecology. In recent years, many restrictions on the publication of geological data have been lifted, and foreign readers can now receive more detailed information on deposits of interest, particularly those of unique genesis and scale.

2004 Volume 46 • ISSN 1075-7015 • Bimonthly
$1359 US/Canada • $1557 Rest of World
http://www.maik.ru/journals/geolore.htm

The journal is indexed/abstracted in *Current Contents Physical, Chemical and Earth Sciences, Science Citation Index Expanded, GeoRef.*

Tel: 800-633-4931
205-995-1567 (outside US and Canada)
Fax: 205-995-1588

INTERPERIODICA
Subscription Office
P.O. Box 1831
Birmingham, AL 35201-1831 USA

IZVESTIYA, PHYSICS OF THE SOLID EARTH
(Fizika Zemli)

Editor-in-Chief
Alexander O. Gliko
Corresponding Member of the Russian Academy of Sciences, Deputy Director, Schmidt Joint Institute of Physics of the Earth, RAS, Moscow, Russia

Fizika Zemli, founded in 1965, publishes results of original theoretical and experimental research in relevant areas of the physics of the earth's interior and applied geophysics. The journal presents results of studies conducted by researchers at the institutes of the Russian Academy of Sciences and other institutions of the Russian Federation. Contributions from foreign authors are also welcome.

The *journal* is indexed/abstracted in *GeoRef, INSPEC.*

2004 Volume 40 • ISSN 1069-3513
Monthly
$1202 US/Canada,
$1329 Rest of World
http://www.maik.ru/journals/physeth.htm

Tel: 800-633-4931
205-995-1567 (outside US and Canada)
Fax: 205-995-1588

INTERPERIODICA
Subscription Office
P.O. Box 1831
Birmingham, AL 35201-1831 USA

Subscribe to the journals from the Russian Academy of Sciences

Translated and Published by MAIK "Nauka / Interperiodica"
(International Academic Publishing Company "Nauka / Interperiodica")
Distributed Worldwide by INTERPERIODICA

Copy this form to mail or fax your order today

	TITLE	Volume	ISSN	ISSUES	RATE IN US DOLLARS US/CAN	RATE IN US DOLLARS INTERNATIONAL	YOUR ORDER
❑	Archaeology, Ethnology and Anthropology of Eurasia (only distribution)	-	1563-0110	4	$200	$265	$ _____
❑	Biophysics	49	0006-3509	6 + 1 Suppl.	$3,575	$3,727	$ _____
❑	Computational Mathematics and Mathematical Physics	44	0965-5425	12	$3,457	$4,206	$ _____
❑	Doklady Earth Sciences	394-399A	1028-334X	9	$4,048	$4,652	$ _____
❑	Doklady Mathematics	69-70	1064-5624	6	$1,980	$2,274	$ _____
❑	Entomological Review	84	0013-8738	9 + 2 Suppl.	$3,668	$4,171	$ _____
❑	Eurasian Soil Science	37	1064-2293	12 + 1 Suppl.	$3,052	$3,515	$ _____
❑	Geochemistry International	42	0016-7029	12 + 2 Suppl.	$3,485	$3,994	$ _____
❑	Geology of Ore Deposits	46	1075-7015	6	$1,359	$1,557	$ _____
❑	Geomagnetism and Aeronomy	44	0016-7932	6	$1,056	$1,213	$ _____
❑	Geotectonics	38	0016-8521	6	$824	$893	$ _____
❑	Herald of the Russian Academy of Sciences	74	1019-3316	6	$2,467	$3,135	$ _____
❑	Izvestiya, Atmospheric and Oceanic Physics	40	0001-4338	6	$1,247	$1,339	$ _____
❑	Izvestiya, Physics of the Solid Earth	40	1069-3513	12	$1,202	$1,329	$ _____
❑	Journal of Communications Technology and Electronics	49	1064-2269	12	$4,012	$4,613	$ _____
❑	Journal of Computer and Systems Sciences International	43	1064-2307	6	$2,889	$3,322	$ _____
❑	Journal of Ichthyology	44	0032-9452	9 + 2 Suppl.	$3,159	$3,635	$ _____
❑	Laser Physics	14	1054-660X	12	$2,467	$2,978	$ _____
❑	Oceanology	44	0001-4370	6	$1,127	$1,208	$ _____
❑	Paleontological Journal	38	0031-0301	6 + 6 Suppl.	$3,831	$4,415	$ _____
❑	Pattern Recognition & Image Analysis	14	1054-6618	4	$973	$1,114	$ _____
❑	Petroleum Chemistry	44	0965-5441	6	$3,955	$4,107	$ _____
❑	Petrology	12	0869-5911	6	$1,365	$1,564	$ _____
❑	The Physics of Metals and Metallography	97-98	0031-918X	12 + 2 Suppl.	$3,837	$4,420	$ _____
❑	Physics of Particles and Nuclei	35	1063-7796	6 + 1 Suppl.	$4,064	$4,317	$ _____
❑	Physics of Particles and Nuclei, Letters	1	1547-4771	6	$4,064	$4,317	$ _____
❑	Polymer Science. Series A	46	0965-545X	12	—	—	$ _____
❑	Polymer Science. Series B	46	1560-0904	6	—	—	$ _____
❑	Polymer Science. Series C	46	Pending	1	—	—	$ _____
	Polymer Science. Ser. A+B+C	46	—	19	$4,440	$5,133	$ _____
❑	Proceedings of the Steklov Institute of Mathematics	244-247	0081-5438	4 + 2 Suppl.	$1,992	$2,296	$ _____
❑	Russian Journal of Inorganic Chemistry	49	0036-0236	12 + 1 Suppl.	$4,348	$5,000	$ _____
❑	Russian Journal of Mathematical Physics	11	1061-9208	4	$856	$973	$ _____
❑	Russian Journal of Physical Chemistry	78	0036-0244	12 + 1 Suppl.	$4,287	$4,935	$ _____
❑	Russian Metallurgy (Metally)	—	0036-0295	6	$2,110	$2,299	$ _____
❑	Stratigraphy and Geological Correlation	12	0869-5938	6	$1,365	$1,564	$ _____
❑	Studies on Russian Economic Development	15	1075-7007	6	$982	$1,127	$ _____
❑	Thermal Engineering	51	0040-6015	12	$2,104	$2,415	$ _____
❑	Thermophysics and Aeromechanics (only distribution)	11	0869-8643	4	$842	$1,010	$ _____

TOTAL _____

❶ Name _____
Institution _____
Address _____
_____ State _____
City _____ Country _____
Zip/Postal Code _____
Telephone (_____)

Delivery is not made until payment is received

To order by phone call **1 800 633-4931**
or (205) 995-1567 outside the US and Canada

❷ ❑ My payment for $_____ is enclosed.
OR
❑ Bill me. My library's purchase order number is _____

❸ Send this order and payment to:
INTERPERIODICA
P.O. Box 1831
Birmingham, AL 35201-1831
Or fax this order form to (205) 995-1588

Order now for immediate delivery. All journals will be published in 2004!

MAIK "Nauka/Interperiodica" Publishing

is pleased to present to the international scientific community simultaneous Russian- and English-language publication of the journals of the Russian Academy of Sciences

MAIK "Nauka/Interperiodica" 2004 volumes include the following titles:

- *Archaeology, Ethnology and Anthropology of Eurasia**
- *Biophysics*
- *Computational Mathematics and Mathematical Physics*
- *Doklady Earth Sciences*
- *Doklady Mathematics*
- *Entomological Review*
- *Eurasian Soil Science*
- *Geochemistry International*
- *Geology of Ore Deposits*
- *Geomagnetism and Aeronomy*
- *Geotectonics*
- *Herald of the Russian Academy of Sciences*
- *Izvestiya, Atmospheric and Oceanic Physics*
- *Izvestiya, Physics of the Solid Earth*
- *Journal of Communications Technology and Electronics*
- *Journal of Computer and Systems Sciences International*
- *Journal of Ichthyology*
- *Laser Physics*
- *Oceanology*
- *Paleontological Journal*
- *Pattern Recognition and Image Analysis*
- *Petroleum Chemistry*
- *Petrology*
- *Physics of Particles and Nuclei*
- *Physics of Particles and Nuclei, Letters*
- *Polymer Science, Series A*
- *Polymer Science, Series B*
- *Polymer Science, Series C*
- *Proceedings of the Steklov Institute of Mathematics*
- *Russian Journal of Inorganic Chemistry*
- *Russian Journal of Mathematical Physics*
- *Russian Journal of Physical Chemistry*
- *Russian Metallurgy (Metally)*
- *Stratigraphy and Geological Correlation*
- *Studies on Russian Economic Development*
- *The Physics of Metals and Metallography*
- *Thermal Engineering*
- *Thermophysics and Aeromechanics**

* *Archaeology, Ethnology and Anthropology of Eurasia* is only distributed by MAIK "Nauka/Interperiodica" Publishing
* *Thermophysics and Aeromechanics* is only distributed by MAIK "Nauka/Interperiodica" Publishing

Please direct all inquiries about the above journals to: **INTERPERIODICA**, P.O. Box 1831, Birmingham, AL 35201-1831.
For faster service call toll-free (800) 633-4931 or (205) 995-1567 (outside US and Canada). Fax: (205) 995-1588, E-mail: interperiodica@ebsco.com

- *Applied Biochemistry and Microbiology*
- *Automation and Remote Control*
- *Biochemistry (Moscow)*
- *Biology Bulletin*
- *Colloid Journal*
- *Combustion, Explosion, and Shock Waves**
- *Cosmic Research*
- *Differential Equations*
- *Doklady Biochemistry and Biophysics*
- *Doklady Biological Sciences*
- *Doklady Chemistry*
- *Doklady Physical Chemistry*
- *Fluid Dynamics**
- *Functional Analysis and Its Applications**
- *Glass Physics and Chemistry*
- *High Energy Chemistry*
- *High Temperature*
- *Human Physiology*
- *Inorganic Materials*
- *Instruments and Experimental Techniques*
- *Journal of Analytical Chemistry*
- *Journal of Applied Mechanics and Technical Physics**
- *Journal of Evolutionary Biochemistry and Physiology*
- *Journal of Mining Science**
- *Journal of Structural Chemistry**
- *Kinetics and Catalysis*
- *Lithology and Mineral Resources*
- *Mathematical Notes**
- *Microbiology*
- *Molecular Biology*
- *Problems of Information Transmission*
- *Programming and Computer Software*
- *Protection of Metals*
- *Radiochemistry*
- *Russian Chemical Bulletin**
- *Russian Journal of Applied Chemistry*
- *Russian Journal of Bioorganic Chemistry*
- *Russian Journal of Coordination Chemistry*
- *Russian Journal of Developmental Biology*
- *Russian Journal of Ecology*
- *Russian Journal of Electrochemistry*
- *Russian Journal of General Chemistry*
- *Russian Journal of Genetics*
- *Russian Journal of Marine Biology*
- *Russian Journal of Nondestructive Testing*
- *Russian Journal of Organic Chemistry*
- *Russian Journal of Plant Physiology*
- *Russian Microelectronics*
- *Siberian Mathematical Journal**
- *Solar System Research*
- *Theoretical and Mathematical Physics**
- *Theoretical Foundations of Chemical Engineering*
- *Water Resources*

* *The journal* is produced under contracts between Plenum Publishing and the Russian Academy of Sciences and/or its divisions, the institutes, and the editorial boards, and under contract and subcontract between Kluwer Academic/Plenum Publishers and MAIK "Nauka/Interperiodica"

Please direct all inquiries about the above journals to: **Springer Science+Business Media, Inc.**, P.O. Box 322, 3300 AH Dordrecht, The Netherlands. Phone: (31 78) 657-6000. Fax: (31 78) 657-6474, E-mail: orderdept@wkap.nl

- *Acoustical Physics*
- *Astronomy Letters*
- *Astronomy Reports*
- *Crystallography Reports*
- *Doklady Physics*
- *JETP Letters*
- *Journal of Experimental and Theoretical Physics*
- *Optics and Spectroscopy**
- *Physics of Atomic Nuclei*
- *Physics of the Solid State*
- *Plasma Physics Reports*
- *Semiconductors*
- *Technical Physics*
- *Technical Physics Letters*

**Optics and Spectroscopy*: Optical Society of America, 2010 Massachusetts Ave., NW, Washington, DC 20036-1023, Attn.: Publications Department. Tel. (202) 223-8130, (800) 582-0416. Fax: (202) 416-6140.

Please direct all inquiries about the above journals to: **American Institute of Physics**, Circulation and Fulfillment Services, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502 USA. Tel. (516) 576-2270, 1-800-344-6902. Fax: (516) 349-9704, E-mail: subs@aip.org

International Academic Publishing Company "Nauka/Interperiodica" (MAIK "Nauka/Interperiodica")
Profsoyuznaya ul., 90, Moscow, 117997, Russia, Phone: 7 (095) 336-1600; Fax: 7 (095) 336-0666,
E-mail: compmg@maik.ru, http://www.maik.ru